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ORE-DEPOSITION AT ASPEN, COLORADO.

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SUMMARY.

Aspen is situated in Colorado, at the west base of the Sawatch range. The main formations of the district, are, in ascending succession, pre-Cambrian granite, Cambrian quartzite, Silurian dolomite, Devonian sandy and shaly beds, Lower Carboniferous dolomite and limestone, Upper Carboniferous shales, Upper Carboniferous sandstones, Triassic red sandstones, Juratrias sandstones and shales, and Cretaceous sandstones, limestones and shales. There are two types of intrusive rock—diorite porphyry and rhyolite porphyry, each if which occurs mainly as a single sheet. The diorite porphyry is like the intrusive rock of the Elk Mountains, lying to the west; the rhyolite porphyry is identical with the white porphyry of Leadville, on the other side of the Sawatch range. The main sheet of rhyolite porphyry at Aspen is at the base of the Weber shales, and an important sheet in Leadville is in the same geological position, the shales having acted as a relatively impermeable blanket to the ascending molten rock, in each case. Both the intrusive rocks (diorite porphyry and rhyolite porphyry) belong to the Late Cretaceous–Early Tertiary period.

The injection of the igneous rocks was practically contemporaneous with faulting, which took place after the deposition of the Laramie Cretaceous; but the intrusion was of brief duration,

while the crustal disturbance was prolonged. The first important movement was an uplift along the axis of the present Sawatch range, upending and dragging up the sedimentary beds on the flanks of the granite. At about the same time there was a lateral thrust from the west, probably caused by the great diorite intrusion of the present Elk Mountains. This caused narrow, close folding, which culminated in faulting. Also the Sawatch range uplift was accompanied by faulting, principally accomplished by the slipping of one upturned stratum upon another, with the weakest beds as gliding-planes. These "bedding faults" were extensive and important.

Synchronously with these other movements there began in the Aspen district, a very local doming-up, such as would arise from a vertically-exerted force. This doming was accompanied and aided by faulting. The movement was probably due to the slow upward propulsion of a column of molten rock, which never reached the surface.

Following considerable folding and faulting came the deposition of metallic sulphides, and ore was formed along faults and fractures. The epoch of ore-deposition was very short, compared with that of the faulting; and after the ore-deposition the faulting continued. The area of domal uplift above mentioned is also the area of main ore-deposition, and within this uplifted and broken area the ore has formed with an unknown vertical extent. There is evidence that the ore-bearing solutions ascended vertically along fault-fissures, and that the actual ore-deposition depended primarily upon precipitative reactions with certain formations, and secondarily upon the influence of intersecting channels. The most important horizon of deposition was at the base of the Weber shales, for the double reason that the relatively soft shales, in which fissures were poorly developed, dammed back the ascending solutions, and that the shales acted, chemically, as a precipitant. The ores were doubtless deposited by hot ascending solutions, representing a phase of an igneous magma, the extreme product resulting from magmatic differentiation.

The primary ore-deposition, though very short, had three dis-

tinct successive stages: (1) Barite veins, (2) silver sulphides, sulphantimonites and sulpharsenites, (3) galena and blende. Slight but well-marked faulting movements accompanied and intervened between these. The first and second stages above noted were more restricted areally as well as much less abundant quantitatively, than the third stage; yet the main profits of the camp have been derived from ores of the second stage.

The superficial descending surface waters have deposited native silver, chiefly by the dissolving of the rich ores of the second stage above noted, and the precipitation of these solutions on coming into contact with the shales. Secondary silver sulphides are noticeably wanting, a circumstance which is believed to be correctly explained by the presence of the chemically active shales.

The stages of primary ore-deposition noted at Aspen correspond with stages suggested as almost universal by the writer, in an earlier paper;[1] but in the reverse order from the usual one. If the usual order results from a gradually lowering temperature, then this reversed order must have resulted from a gradually rising temperature. This rising temperature is accounted for theoretically by the slow upward movement of the molten volcanic plug above referred to.

The further general deduction is made that a maintained equable temperature during the critical epoch of ore-deposition results in separate and well-defined mineral zones, not overlapping; but that if the epoch of ore-deposition falls upon a period of rising or of falling temperature, the different zones, migrating, would be deposited one after the other, to a certain extent in the same locality.

INTRODUCTION.

Thirteen years ago the writer spent a year in a study of the geology and ore-deposits of the notable mining camp of Aspen, in Colorado. The results were published in Monograph XXXI. of the U. S. Geological Survey. It was necessary to complete this study rather hastily, and several branches of the investigation were prematurely nipped off—particularly that which concerned the origin of the rich silver sulphide ores of the Smuggler, Molly

[1] ECON. GEOL., Vol. II., No. 8, p. 791.

Gibson and other mines of the district, as distinguished from that of the lead-zinc ores which form a distinct class.

Later, the printed descriptions were interpreted by another writer[1] as favoring the explanation that the rich silver sulphides were derived from the low-grade (in respect to silver) lead-zinc ores, by descending surface waters.

Lately the writer has had opportunity to again visit the camp, to make a thorough study of one of the mines, and to go over the entire evidence as to the district, in the light of his intervening experience. The result was to confirm most of his early conclusions, to modify some, and to establish some new points. It is believed that a concise summary of the conditions of ore-deposition as at present understood by him, will be of interest.

LOCATION.

Aspen is situated at the west base of the Sawatch range, the central range of the Rocky Mountains in Colorado.

ROCK FORMATIONS.

SEDIMENTARY ROCKS.

A great range of sedimentary formations is exhibited at Aspen, within a very small space.

The lowest formation is a pre-Cambrian granite. This is overlain by a Cambrian quartzite, 200 to 400 feet thick; and this by a Silurian dolomite 250 to 400 feet thick. Above this come about 60 feet of shaly dolomitic and quartzitic Devonian sediments, collectively called the Parting quartzite series. Overlying the Parting quartzite is a Lower Carboniferous dolomite, averaging 200 to 250 feet thick, and above the dolomite is a Lower Carboniferous limestone 100 to 150 feet thick. Above this comes a thousand feet or more of thin-bedded carbonaceous limestones and calcareous and carbonaceous shales, called the Weber formation. Overlying the Weber is a great thickness (approximately 4,000 feet) of mixed sandy and limy sediments, with a general dark

[1] W. H. Weed, "Enrichment of Mineral Veins by Metallic Sulphides," *Bul. Geol. Soc. Am.*, Vol. XI., p. 202.

red color (Maroon formation). These have been referred to the Upper Carboniferous. These are overlain by lighter red sandstones which have been assigned to the Triassic, and are estimated as about 2,600 feet thick at this point. Still higher comes a series some 275 to 325 feet thick, consisting of gray sandstones and shales, of supposedly late Juratrias age (Gunnison formation). Overlying this formation, in turn, comes a thick series of Cretaceous sediments, beginning with the Dakota sandstone (250 feet); then come the Colorado formation (450 feet), the Montana formation (4,000 feet) and the lower part of the Laramie.

These sedimentary beds have been upturned steeply, so that at the town of Aspen the entire section is shown in a belt two miles wide.

INTRUSIVE ROCKS.

There are two distinct types of intrusive rock in Aspen—a rhyolite porphyry (or quartz-porphyry, according to the older nomenclature), and a diorite porphyry.

The diorite porphyry is a dark green, fine-grained rock, occurring, within the mining district, principally in a single sheet, parallel to the bedding of the sedimentary rocks, or cutting across it at a slight angle. This sheet pinches out at the town of Aspen and was followed for three and a half miles to the south, by which time it had increased to a thickness of 150 feet. It gradually cuts obliquely across the formations from the horizon of the Devonian at the south end of the mapped area, to the base of the Cambrian, at the point where it dies out on the north. South of the area mapped this sheet was observed at several points, always thickening, and it undoubtedly runs into the great diorite mass of Castle Peak, ten miles away. Castle Peak is a complex of dikes and sheets of eruptive rock in the Maroon Carboniferous beds. Still further south this complex changes to solid diorite, as shown in the adjacent White Rock Mountain, which is a part of the great body of diorite found all along the axis of the Elk Mountains.

The rhyolite porphyry or quartz-porphyry is a nearly white

rock, identical in character with the white porphyry of Leadville, which is across the Sawatch range from Aspen. This porphyry at Aspen (as at Leadville) occurs as a sheet which is approximately conformable to the bedding of the sedimentary rocks, but which locally cuts across it. It usually lies near the base of the Weber shales, and its average normal thickness is perhaps 250–450 feet.

This sheet has been cut out by a fault running slightly oblique to the stratification, in the northern part of the mining district.

There are also several cross-cutting, nearly vertical, dikes of the rhyolite porphyry, which probably connect with the sheet, and which probably represent the channels along which the molten rock ascended. These fissure-channels were probably obstructed or even terminated on passing from the rigid lower formations into the Weber shales, and the material lifted the overlying strata, instead of penetrating them, and spread out at the base of the shales, in the form of the present sheet. The corresponding White porphyry of Leadville also has one of its main sheets at this horizon, and for the same reason.

Both the intrusive rocks at Aspen (the diorite porphyry and the rhyolite porphyry) belong to the Late Cretaceous–Early Tertiary period.[1] Both were injected toward the beginning of the great mountain-making disturbance which characterized that period, but before the greater part of the folding and faulting.

FOLDING AND FAULTING.

Folding took place in the Aspen district after the deposition of the Laramie, and was partially contemporaneous with the injection of the intrusive rocks. It is probable that folding, faulting and intrusion began simultaneously, and that the injection of the molten rock occupied only a comparatively brief period of time, while the strains which were generated at the same time found relief very slowly, in folding and faulting. A continuation of the same force, therefore, which thrust the intrusive rocks into the sedimentary beds brought about the folding and breaking of these intrusive sheets along with the enclosing strata.

[1] See J. E. Spurr, Professional Paper, 63, p. 120.

The first important movement, which has undoubtedly continued until the present day, was a gradual uplift along the axis of the present Sawatch range. Thus the sedimentary beds lying on the basal granite were upended and dragged up on the flanks of the growing granite range. At about the same time there was a lateral thrust from the west, probably due to a great intrusion of diorite along the axis of the present Elk Mountains. This jammed the sedimentary beds against the Sawatch granite buttress, producing, chiefly, a narrow belt of overthrust, easterly dipping folds, which culminated in a great fault (the Castle Creek fault), originating along the axis of the principal overthrust anticline. This fault has a maximum vertical element of dislocation, as measured on a vertical cross-section, of about 9,000 feet, the upthrown side being that of the Sawatch range.

The uplift of the Sawatch range, and the up-dragging of the sedimentary rocks at its base was accompanied in the Aspen district by slipping of one bed upon another, those lying nearer the granite slipping upward past those further away. These slips were localized along the weaker beds, and are frequently faults of very great displacements. The actual displacement is, however, usually difficult to estimate or to realize, on account of the approximate parallelism of the movement with the bedding.

The chief of these faults occurs at the base of the Weber formation. It appears probable that the total displacement along this fault must be thousands of feet. Cutting slightly across the stratification locally, it has, in the northern part of the district, eliminated whole formations from the normal column. Movement along this fault began early in the mountain-building disturbance, and is still progressing. Other faults of this system occurred along the contact of the Lower Carboniferous limestone and the dolomite of the same age; another along the contact of the Weber and Maroon formations; and another along the Parting quartzite beds. The growth of these faults has as a rule not been so rapid that they are now expressed at the surface by simple fault-scarps, since concomitant erosion has been active enough to keep these planed down. In several minor cases, however, faults in this same district have grown so rapidly that they

have outstripped erosion, and have formed simple fault scarps. It appears certain, also, that most of the uplift of the rocks along the great bedding faults operated directly to elevate the Sawatch range, even though the "corners" of the scarps at the base of the range were well rounded and planed—hence that the range owes much if not most of its relief to the faulting at its margin, which is still progressing.

Synchronously, so far as can be judged, with the beginning of the Sawatch range uplift (which produced the great "bedding-faults" described), and the intrusion of the Elk Mountains diorite mass (which produced the sharp folding and attendant faulting mentioned), there began in the Aspen district a very local uplift such as would arise from a vertically exerted force. This was a doming-up of the rocks (including the granite) just east of the Castle Creek fault, and extending north and south over a limited area. The doming was accompanied and aided by faulting, which continued from that time till the present. The summit of the dome was broken by intersecting fractures, which bounded numerous fault-blocks which moved one upon the other as the domal uplift continued. The total maximum vertical movement caused by this doming is estimated at about 5,000 feet.

At the time of the writer's first examination of the Aspen district it was reasoned out that this domal uplift was due to the upward slow propulsion of a column or pipe of molten igneous rock, which never reached the surface; and the belief in the probability of this hypothesis has since been strengthened.

PRIMARY ORE DEPOSITION.

Following considerable faulting and fracturing at the beginning of the uplift and disturbance came the deposition of metallic sulphides. Ores have been universally found in this district along faults and fractures, either along vertical or steeply dipping faults, or, more commonly, at the intersection of steeply dipping ones with flatter ones. The entire epoch of ore-deposition was short compared with the faulting. Some of the faulting took place previous to this epoch of ore-deposition, and along channels thus opened the ore has formed. Some of the faulting was sub-

sequent, and the ore is displaced and broken up by these barren faults.

The domal uplift in the center of the Aspen district has already been mentioned. On account of its peculiar deformation this region (which is a few miles in diameter and, as before stated, is lifted, in the center, about a mile above the surrounding region) becomes isolated and conspicuous, even amid the tremendous folding and faulting which the adjacent areas show; and its difference from these adjoining areas becomes even more significant when it is considered that the center of greatest uplift and disturbance has also been the chief center of ore-deposition. The surface extent of the district which has been actually largely productive of ore is practically identical with that of this faulted and uplifted region, which is centralized in Tourtelotte Park and Aspen Mountain, and on whose borders are Smuggler Mountain on the one side and the deposits along the Castle Creek fault in Queen's Gulch and southward on the other.

Within this uplifted and broken area ore has formed with an unknown vertical extent. The existing mine workings have a great range of elevation—about 3,500 feet—between the extreme limits of which (the surface on the one hand and the lowest mine workings on the other) no change in the nature of the deposits that could be referable to relative elevation was detected. It is probable that the original ore-deposits extended far above the present surface, and that they extend considerably deeper than exploration has attained.

All the earlier-formed faults in and near this dome became the site of ore-deposition. Some of the most notable deposits took place on the northern slope of the dome, in Aspen and Smuggler mountains. Near the central and broader portion of the dome, the ore-deposition, which is coincident with the faulted area, occupies a wide belt; on the north, as the domal structure fades out and is effaced by the dominant powerful folding and faulting parallel to the northeast axis of the Sawatch range, and caused by the uplift of that range, the zone of faulting becomes narrower, as measured horizontally, and the coincident belt of ore-deposi-

tion becomes confined chiefly to the region of one or two of the main great bedding faults.

The dips of the beds in the region, even where most steeply upturned, are always (except locally) away from the range. There is evidence that the solutions which deposited the ores were ascending, and that they ascended, so far as possible, vertically from below, therefore in general passing through the granite and up into successively higher formations. Ore in greater or less amounts has been found along the fault channels down through the whole range of sedimentary formations, and even in the granite. While thus the path of the solutions is well established, the actual ore-deposition depended primarily upon precipitative reactions with certain formations as compared with others and secondarily but to a very important degree to the influence of intersecting channels (usually fault-channels) which doubtless brought about the maximum precipitation by the mingling of solutions differing chemically (on account, perhaps, of the different rocks traversed).

The ore taken out from faults in the granite and in the Cambrian quartzite was trifling in amount; locally, large amounts of ore were taken out from the Silurian dolomite, along faults; and the Lower Carboniferous dolomite and limestone were highly productive formations.

But the most important ore-horizon was at the base of the Weber shales, at the contact of this formation and the underlying limestone or dolomite. This contact is usually formed by the great fault (called the Silver fault) which runs very nearly parallel to the bedding; and along this fault the most extensive mineralization took place. Above this horizon, in the Weber shales, very little ore indeed was deposited. Along other faults (other than the Silver fault) also, where the Weber shales lie on one side, it was noted that ore has been frequently deposited in abundance. It is clear, therefore, that the ore-bearing solutions rose through the underlying siliceous formations (granite and quartzite) with little precipitation; and through the overlying dolomitic and calcareous formations (Silurian and Lower Carboniferous) with much precipitation; and that on encountering the overlying

Weber shales and the porphyry sheet which had been intruded at the base of the shales, the solutions were dammed back (very much as the molten rhyolite porphyry had been before), and the maximum circulation was diverted along the Silver fault. It is clear, in addition, that the shales reacted powerfully chemically on the solutions, to produce precipitation. A large amount of ore was also deposited along the bedding fault which lies between the Lower Carboniferous dolomite and the Lower Carboniferous limestone.

In the original Aspen report, it was concluded that the ores had been deposited by hot ascending solutions, and this view is still strongly held.[1] It was also pointed out that there were three distinct types of vein-formation regarded as primary: the galena-blende ores, low grade in respect to silver; the very rich silver sulphide, sulphantimonite and sulpharsenite ores; and the barite veins. In the later examination this division has been proven, and the primary nature of all three has been demonstrated. Most of the new and more conclusive evidence came from an examination and detailed study of the Smuggler mine, but the results obtained accord with previous knowledge available concerning other mines.

To crystallize and illustrate clearly the situation the history of events in the Smuggler mine may be summarized.

Faulting began in the Smuggler mine with the development of the Silver fault, nearly parallel to the stratification, at the base of the Weber shales. This fault strikes northeast and dips about 65 degrees northwest. Next was developed a fault (the Smuggler-Gibson fault) striking northwest and dipping 30 degrees southwest, which displaced the Silver fault, and made a flat bench in the contact,[2] with the shales lying above this bench, and the dolomites of the Carboniferous and the Silurian lying below. Sub-

[1] The supposition originally held, that the ascending hot solutions derived their metallic contents by leaching rocks through which they passed, is, however, no longer entertained by the writer, who now regards these solutions as a phase of an igneous magma, the result of extreme magmatic differentiation.

[2] Between the shales above the Silver fault and the Carboniferous dolomite below it.

sequently the movement along the bedding planes was resumed and therefore renewed movement took place along the Silver fault. A similar movement took place along the Parting quartzite (Devonian) which belonged to the block beneath the Smuggler-Gibson fault. This movement (the Clark fault), harmonizing with that of the Silver and other bedding faults (being the dragging up of the block on the southeastern side, nearer the Sawatch range, past that on the northwestern side, further away from the range, the whole recording the further growth of the mountains), separated the flat bench of the Smuggler-Gibson fault into two portions—an upper and a lower bench. The vertical component of the movement (which was actually oblique) along the Clark fault at this period was about 250–350 feet.

Directly after this movement ore-deposition occurred along all of the faults mentioned. As stated above, it consisted of three distinct and separate though closely successive stages, each separated from the other, and probably each accompanied by movements along the faults, showing the growth of these—especially the bedding faults (the Silver and Clark faults), whose continued movement recorded the steady growth of the range; yet the total time consumed by all these ore-deposition stages was relatively so short that the accompanying movement along the fault-planes was so slight as hardly to be measured with any accuracy. The movement subsequent to all ore-deposition, however, was, again, very important: on the Clark fault this post-mineral movement had a vertical component, as measured in a cross-section, of about 400 feet. In other words, the Clark fault represents one of the later-formed bedding faults, and gradually grew so that the vertical component of the dislocation amounted to some 750 feet; and the ore-deposition, consisting of three distinct stages, took place along that fault within so short a space of time that it seems almost a mere point as compared with that occupied by the steady faulting. The general observations made above for the district, as to the relatively short space which the ore-deposition occupied as compared with the faulting, is here startlingly emphasized; and

it is clear in this case, as it was in another recently described,[1] that the ores were not deposited under conditions long operative, but were injected and crystallized in a definite and brief period more comparable to the time required for the injection and solidification of an igneous rock intrusion (that of the rhyolite porphyry, for example) than anything else.

We may pass next to the history and stages of mineralization, as illustrated in the Smuggler mine.

The first stage was the deposition of barite in regular veins, following mainly the stratification, along and near the bedding faults, and giving evidence of having formed in open fissures. These veins are often barren, and it is probable that the earlier ones were formed previous to any deposition of metals.

This barite deposition was immediately followed, with no sharp break, by the deposition of sulphides, sulphantimonites and sulpharsenites of silver, or silver and copper. The minerals include polybasite, argentite, tetrahedrite and tennantite. These sulphides frequently filled slight crevices in the barite veins, such crevices being the result of strain subsequent to the crystallization of the barite; elsewhere they occur in veinlets distinctly subsequent to the barite, forming on the whole, bodies of unequalled richness; and occasionally they seem to occur intercrystallized and nearly contemporaneous with the barite. It is plain that the silver sulphide deposition was subsequent to and distinct from the barite deposition, but that there was no break between the two. The trend of the main silver sulphide shoots, which were limited of extent, and clean cut, was different from that of the barite veins in general, being nearly east and west.

The principal shoot formed the rich ore-body of the Smuggler and Molly Gibson mines. In the Molly Gibson mine, which contained most of this excessively rich silver ore, dividends of around $4,000,000 dollars were paid from it, within a short time.

After the above events, a marked, but probably not very extensive renewed movement took place along the "bedding" faults (the Clark and the Silver faults) producing a strong brecciated

[1] "Ore-Deposits of the Velardena Dist., Mex.," ECON. GEOL., Vol. III., No. 8, pp. 713, 714.

zone along these faults, which brecciation involved much of the barite veins and the rich silver sulphides near these faults. Along these brecciated zones waters rose and deposited large quantities of galena, very low grade in respect to silver, and of blende. This constitutes the "milling ore" of the district.

In his earlier report the writer recognized these three stages, and that they were all primary and due to ascending solutions,[1] and so described them. He also recognized the fact that the rich silver sulphides were later than the accompanying barite; but did not clearly observe the relations between the rich silver shoots and the lead-zinc ores. He hazarded the conjecture that the barite and silver sulphides were later than the lead-zinc ores. The reverse is now definitely shown to be true. On account of this uncertainty, however, the writer was unable to deny the possibility that the rich silver sulphides were due to concentration of silver from the low grade lead-zinc ores by descending waters, when this explanation was advanced by Mr. Weed.[2] This, however, is now shown to be out of the question. Specimens of polybasite ore from the Smuggler (both with and without barite), which had been crushed and brecciated, and cemented by galena, were seen by the writer; and the occurrence of angular fragments of barite, frequently containing slightly later silver sulphides, in the heavy breccia which has been cemented by the galena-blende ores, is shown abundantly in many parts of this mine.

The different stages of ore-deposition and their relations as above sketched undoubtedly holds good through the whole district; and all available records conform to this interpretation.

The lead-zinc ores are found throughout nearly the whole district, and are everywhere similar. They have everywhere formed by filling the interstices of breccias and by rock-replacement to a more or less marked degree—especially of dolomite or limestone. They contain little or (usually) no barite, except as inclusions of the earlier-formed veins. The barite and the high-grade

[1] Monograph XXXI., U. S. G. S., p. 192, etc.; Monograph XXXI., U. S G. S., p. 188.

[2] *Bull. Geol. Soc. of Am.*, Vol. XI., p. 202.

silver ores are usually quite closely associated, yet not so closely as to argue their contemporaneous origin. Many large barite veins are practically barren of metallic contents;[1] and occasionally rich silver sulphide ore free from barite is encountered. In mines where the barite-rich silver ore and the lead-zinc ore occur together, they are almost invariably in distinct and separate bodies or shoots. Also the barite and silver sulphides are not found in certain parts of the district where the lead-zinc ores occur abundantly.

The review of the evidence shows that the barite-rich silver deposition was more restricted areally as well as much less abundant quantitatively than the lead-zinc deposition; and that the two epochs of deposition were so distinct that the region of the openings cemented by one, while in general it coincided with that of the openings cemented by the other (since both occurred in the same zone of constant weakness), failed entirely of coinciding in many important localities of considerable extent.

WORK OF DESCENDING SURFACE WATERS.

Native silver is very common in the ore beneath the relatively shallow oxidized zone, in which galena and blende has been changed to lead and zinc carbonates. Ordinarily the silver in these carbonate ores is not in the native form, though the writer has seen a specimen of solid lead-zinc carbonate from one of the upper Smuggler levels, which was full of wire silver. The deposition of wire silver, however, is abundant to considerable depths below water level, being found at least up to 900 to 1,000 feet below the surface, even at points where the water level originally stood only a few hundred feet down. In the Smuggler mine, for example, the water (lowered for the last thirteen years by pumping) probably stood originally some 300 feet deep (third level), while locally abundant native silver is found all the way down to the ninth level (around 900 feet) at least. Similarly silver was found in Aspen Mountain principally in the lower mine levels, also at a considerable depth from the surface.

Where native silver occurs in noticeably large quantities, it is

[1] Mon. XXXI., U. S. G. S., p. 227.

usually, so far as noted, close by or in the vicinity of original primary silver sulphides. The process of alteration of these sulphides to native silver has been abundantly observed. The silver is carried certainly a little distance before being precipitated, but probably this distance is on the average very slight indeed. The native silver occurs locally in those faults which have been designated and described above as post-mineral, since they are later than any deposition of sulphides; and here is frequently later than the latest fault movement, since it binds together fragments of the loose breccia. Such occurrences are usually where fragments of the rich silver sulphide ore have been involved in the fault breccia, and the attack of the sulphide by the waters circulating along the fault produces the solution of the silver and its prompt precipitation in the native form. It seems clear that this process is due to ordinary surface waters. It is also clear that the chief agent of precipitation has been and is the Weber shales. The native silver, where it occurs in notable amount, nearly always occurs on that side of the vein or fault zone which is formed by the shales and very commonly is entirely within the shale wall. Though the amount of material thus transformed from sulphide to the native state, by descending surface waters is large, yet it is not probable that the net amount of concentration of ore-values has been very great, for reasons given above.

It is noteworthy and significant that in Aspen the rich secondary silver sulphides, such as occur in many districts, *especially where rich primary silver sulphides occur,* are virtually unknown. At Tonopah, for example, where the primary ore contains abundant argentite, stephanite, polybasite and silver selenide, there have been formed, probably by the action of descending waters, scondary pyrargyrite (ruby silver), argentite and a very subordinate amount of native silver. Similar occurrences have been noted by the writer in other cases, as in the Oaxaca district in Mexico. In these cases the secondary silver sulphides are accompanied by and certainly in large part at least derived from primary silver sulphides almost or equally as rich. The most

characteristic secondary silver sulphide, in these instances, is ruby silver, which is virtually unknown at Aspen.

If we compare the Aspen district with the Georgetown district, also in Colorado, we have two districts in which the climatic conditions, and the time, nature and origin of the general ore deposition are similar, as the writer has shown elsewhere.[1] Yet in Georgetown the secondary silver sulphides, including ruby silver, are abundant, and native silver relatively very subordinate. The essential difference of conditions lies plainly in the factor which has precipitated the native silver at Aspen—the carbonaceous Weber shales (which contain beds of impure coal, often in the very hanging-wall of the fault-veins). Similar rocks are lacking in Georgetown, and, indeed, in the other districts referred to. It seems clear that in the exceptional Aspen instance silver dissolved from rich sulphides has been reduced to native form by the shales; but where such rocks reacting chemically so unusually with the solutions are lacking, and the wall rocks are relatively siliceous, the silver is again precipitated as sulphide. It will be noted that the chemical action of the shales (see p. 311) appears to have been mainly responsible for the original deposition of the metals as sulphides, by hot ascending waters, at a considerable depth from the surface: and later on, close to the surface, for the deposition of secondary native silver by cold descending waters. Evidently, therefore, superficial conditions are necessary for the precipitation of the secondary silver in the native form.

To an action similar to that at Aspen the writer is inclined to ascribe (though without exhaustive evidence) the singular occurrence (yet altogether analogous physically to the occurrence of the native silver at Aspen) of native gold in the Cretaceous shales in the Wapiti mine at Breckenridge, Col., where the gold occurs in leaves and in vugs in shale near much lower-grade sulphide veins, which occur at or near the contact of shale and later intrusive porphyry.

[1] Professional Paper No. 63, U. S. Geological Survey. See pp. 129, 169, etc.

SIGNIFICANCE OF SEQUENCE OF ORE-DEPOSITION.

In an earlier paper,[1] setting forth a theory of ore-deposition, it was proposed by the writer that the most important class of ore-deposits (save of the most common metals) were differentiation products resulting from the siliceous extreme of the differentiation of rock magmas: that the successive steps of this metal-depositing stage of the differentiation followed one another in a normal regular order, and were deposited in successive zones, according to temperature. It was also pointed out that with the downward progress of the cooling of the parent magma (and the consequent sinking of the isogeotherms) the successive zones of mineralization would migrate downward, and successive cementations of successive openings at a single horizon would show the superposition of one zone upon another originally distinctly lower.

A preliminary attempt was also made to define some of the principal zones as follows:

1. The pegmatite zone, containing tin, molybdenum, tungsten, etc., with characteristic gangue minerals, such as tourmaline, topaz, muscovite, beryl, etc.

2. The free gold-auriferous pyrite zone, with coarse quartz gangue.

3. The cupriferous pyrite zone.

4. The galena-blende (galena usually argentiferous) zone.

5. The zone of silver and also much gold, usually associated with metals which combine with them to make substances which are undoubtedly highly mobile, and account for the relatively elevated position of the zone. These associated metals include antimony, bismuth, arsenic, tellurium and selenium. Characteristic minerals of this zone are tellurides and selenides of silver, gold tellurides, argentiferous tetrahedrite and tennantite, polybasite, stephanite and argentite.

6. The zone of earthy gangues, barren of valuable metals.

Referring to the conclusions as to Aspen, we have the following sequence:

1. Barren barite.

[1] ECON. GEOL., Vol. II., No. 8, December, 1907, pp. 781–795.

2. Silver sulphides, sulpharsenites and sulphantimonites.
3. Galena and blende.

Here we have the normal association, corresponding to zones 6, 5 and 4 of the writer's originally proposed sequence, but in inverted order. That this inverted order is actually the reverse of the usual order, the writer's experience leaves him little doubt; and indeed this is the first case of reversal that he has come in contact with. If, however, the usual order results from a gradually lowering temperature, as there seems little reason for doubting, then the reversed order must have resulted in this case from a gradually rising temperature, so that originally lower zones of ore-deposition gradually rose till they overlapped and were superimposed upon zones originally higher.

It was shown by the writer at the time of his first examination of the Aspen district, that the ore-deposition, as well as the faulting, was probably coincident with the upward propulsion of a volcanic plug of probably molten rock, which led to much doming up and breaking of the solid rocks above; and the ore-deposition took place immediately above this plug, from solutions ascending from below. As the doming-up and up-faulting is proved to have been gradual and progressive, the molten plug was evidently gradually ascending for a long period. Under these conditions a given point above would experience a constantly rising temperature, which would be maintained through the brief and critical period of ore-deposition.

Contrasting this condition with the probably commoner relation of intrusion to ore-deposition, we may suppose that at a locality where an igneous intrusion has taken place with relative rapidity and violence, the temperature of a point close by will be greatest at the time of the intrusion, and will gradually diminish as the intruded rock cools; and that the brief and critical magmatic differentiation stage of ore-deposition will normally occur within the period of falling temperature.

The further general deduction may be made in this connection, that where the temperature is maintained at an equable pitch for a long time, and the critical period of ore-deposition occurs within

this period, the zones of metal deposition will be normally one above the other, and will not overlap as they will do if the epoch of ore-deposition falls upon a period of rising or of falling temperature; and that any given zone afterward brought fortuitously to the earth's surface by erosion will show a single stage of ore-deposition, and no more. Further, the amount of overlap of the zones, where these do overlap, will have depended upon the ratio of the rate of change of temperature to the length of the period of ore-deposition. Since there are many reasons which the writer has already put forth for believing that ore-deposition takes place in a very brief period, almost comparable to that occupied by an igneous intrusion, while the change of temperature is certain to be relatively gradual, it can probably be stated more simply that the amount of overlap of the mineral zones will depend upon the rate of the change of temperature; and in proportion as this rate increases, we may find a more and more extensive record of the successive zones, successively superimposed one upon the other.

THE ORIGIN OF THE BOLIVIAN TIN DEPOSITS.

WILLIAM R. RUMBOLD.

INTRODUCTION.

The object of this paper is to prove that in the majority of cases, the popular idea of the origin of the Bolivian tin deposits and of their mode of occurrence is erroneous.

The popular idea, as far as it is known to the writer and at any rate the opinion which it is desired to disprove, is clearly expressed by Dr. A. W. Stelzner, who writes: " The part played in geological history by the tin ore of Bolivia contrasts sharply with that which has been observed in the Erzgebirge of Saxony and Bohemia and in Brittany, Cornwall, East Indies, Australia, Tasmania and the United States of America and which has hitherto been willingly regarded as the exclusive method of tin occurrence. The Bolivian tin ore does not constitute aureoles surrounding plutonic granite and characterized by the contemporaneous presence of minerals containing boron and fluorine. On the contrary it can only be considered as produced simultaneously with precious silver ores and sulphides of Cu, Fe, Pb, Zn, by precipitation from mineral springs, which were connected in point of time and perhaps also as effects with outflows of Cretaceous or Lower Tertiary volcanic rocks."

Again in " A Treatise on Ore Deposits," by Louis and Phillips, page 88, the following passage occurs referring to Bolivia: " The paragenesis is thus utterly different from that of all other known occurrences of tin stone, such minerals as tourmaline, topaz, fluorspar and apatite being conspicuously absent."

In this paper only those tin ore deposits with which the writer is familiar are described, since a few pages based on personal observation, however deficient the writer, are better than many books, which only have hearsay evidence for the foundation of their argument.

The notes on the microscopic character of the rocks associated with the tin deposits will go far to prove the truth of this.

GEOGRAPHICAL.

The part of Bolivia in which the principal tin deposits are situated has Oruro for its center (see map, Plate V). To the northwest lies the tinfield of Tres Cruces or Quimsa Cruz; to the southeast lie the districts of Negro Pabellon, Huanuni, Llallagua, Uncia, Totoral, Antequera and Avicaya.

The Cordillera Real runs in an unbroken line of snow peaks, except for the valley of the La Paz River, from Sorata (highest peak of which is Illampu 21,490 feet) through Huana Potosi and Illimani (21,040 ft.) to Santa Vela Cruz (18,200).

South from Santa Vela Cruz, the Cordillera is lower and more broken and the hills around Oruro can hardly be said to belong to the Cordillera Real.

On the west or Oruro side of the range, the country is a dry bare tableland, between 12,000 and 13,000 feet above sea level, formerly the bed of an ancient inland sea. On the east, the country falls rapidly into the tropical forests of the Amazon and Paraguay.

The southeast district is at the present time by far the most important economically, but as the Tres Cruces field is better known to the writer it will be first described.

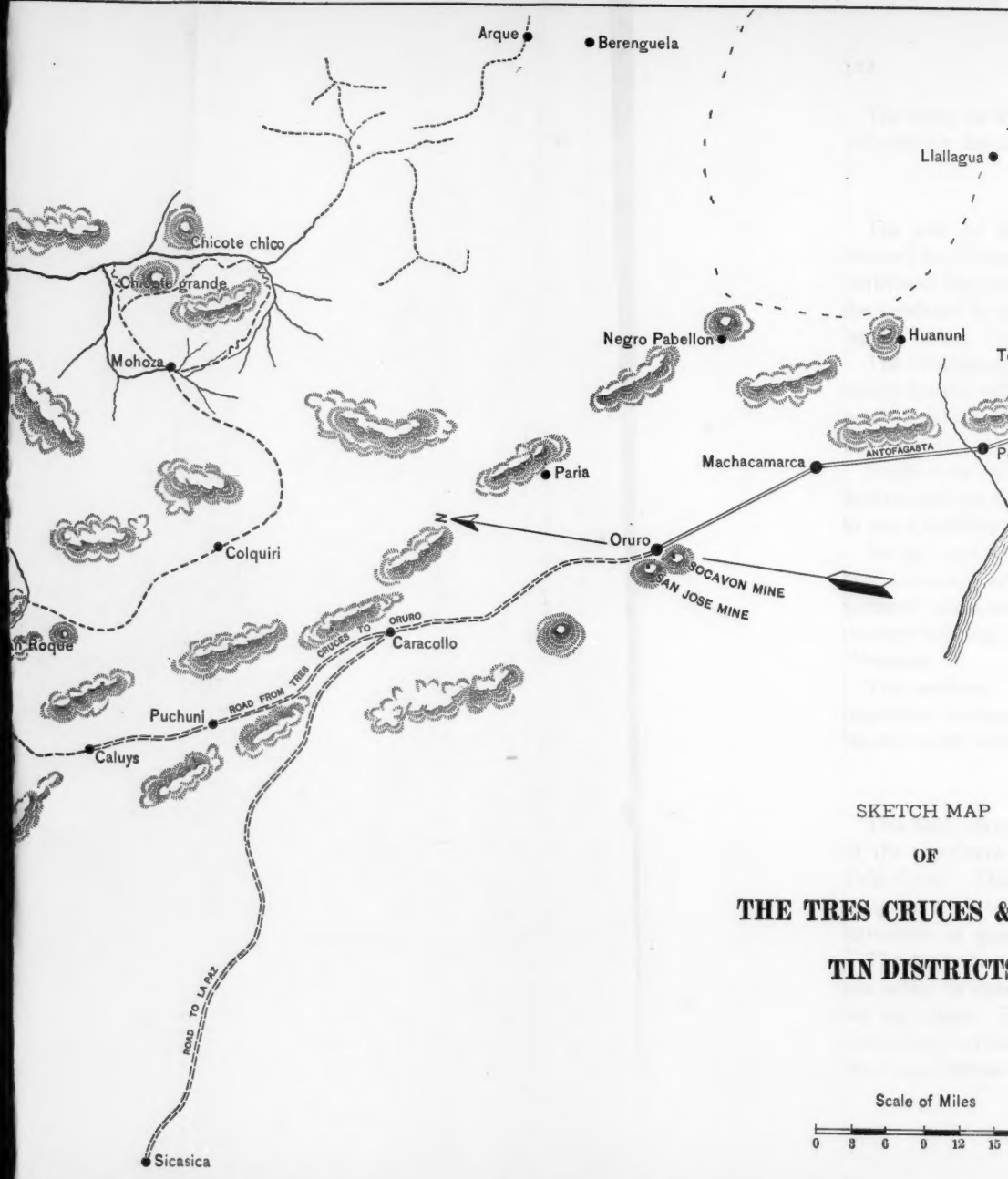
TRES CRUCES TIN FIELD.

This field, about ninety miles north of Oruro, is in the center of the Cordillera Real. It also includes the district of Santa Vela Cruz. The main geological features are simple. They comprise a series of vertical and inclined quartzite schists with intrusions of quartz-porphyry and granite.

The quartzite schist varies from true quartzite through quartzite schist to slate, quartzite schist being the best general name for the rocks. It is often highly contorted and faulted, the contortions varying from a microscopic scale to one as large as the Andes themselves.

PLATE V

River Apopaya
Mohoza
River Quime
River Ichoca
River
Inquisivi
Quime
Pusa
Concordia
San Roque
Santa Vela Cruz
Barossacota
Monte Blanco
Tres Cruces
Cordillera Real
River Iaco
Iaco
Caluys
Luribay



SKETCH MAP

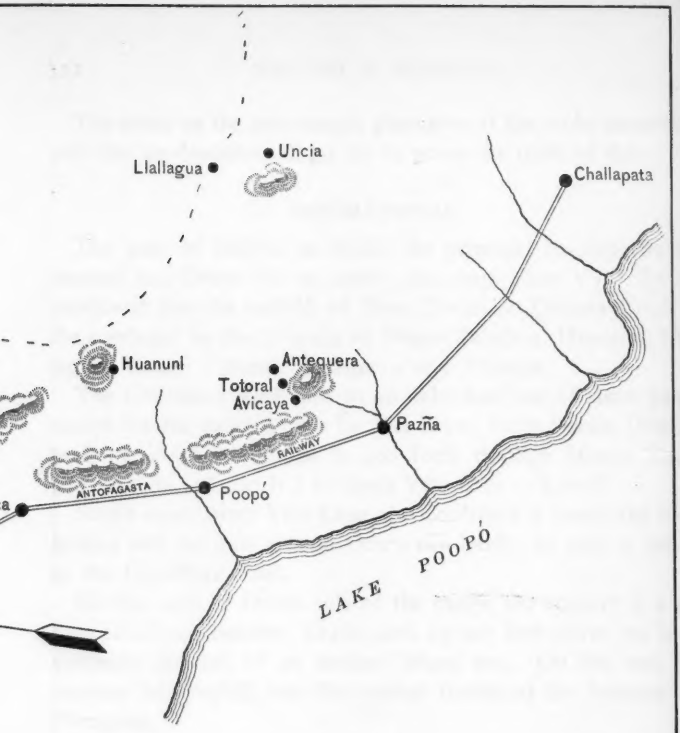
OF

THE TRES CRUCES &

TIN DISTRICTS

Scale of Miles

0 3 6 9 12 15



SKETCH MAP

OF

TRES CRUCES & ORURO TIN DISTRICTS

Scale of Miles

0 3 6 9 12 15 18

The general dip of the strata is vertical and the strike follows the direction of the axis of the range, approximately north and south. The quartzite schist is usually considered unfossiliferous, but in the Concordia mine (Santa Vela Cruz) a number of trilobites have fortunately been found. The best specimen was sent to England and has been pronounced by Mr. Lake, of Cambridge University, to be a new species of the genus *Dalmanites,* which fixes the age of the beds as Devonian.

The volcanic rocks are (1) quartz parphyry, (2) granite. The quartz porphyry is of the usual type and is found as dykes and bosses intruding the quartzite schist. A more detailed description of this rock will be found in the microscopic notes. The granite has never been seen is place, but from the position of fragments picked up from streambeds it presumably occurs in the north west part of the district. The fragments contain both orthoclase and plagioclase felspar, biotite mica and quartz. It is coarse but even-grained.

THE CONCORDIA MINE.

This mine is first described because of the interesting character of the deposit and the exceptional opportunities it afforded for study.

It is situated on the east side of the Santa Vela Cruz group of mountains at an altitude of 16,000 feet above sea level. The country rock comprises a series of beds passing through all gradations from quartzite to quartzite schist; the general strike of the beds is north and south and the dip vertical. Microscopically the rock is found to consist of quartz granules, muscovite and biotite mica with tourmaline and pyrite as accessory minerals. It is usually dark gray in color, with bedding and cleavage planes well developed. Occasionally belts of a granular, white quartzite occur, which do not follow the bedding planes and which are almost invariably favorable for tin, the lodes which pass through those belts being enriched and the rock itself containing cassiterite disseminated through it, generally accompanied by considerable quantities of tourmaline.

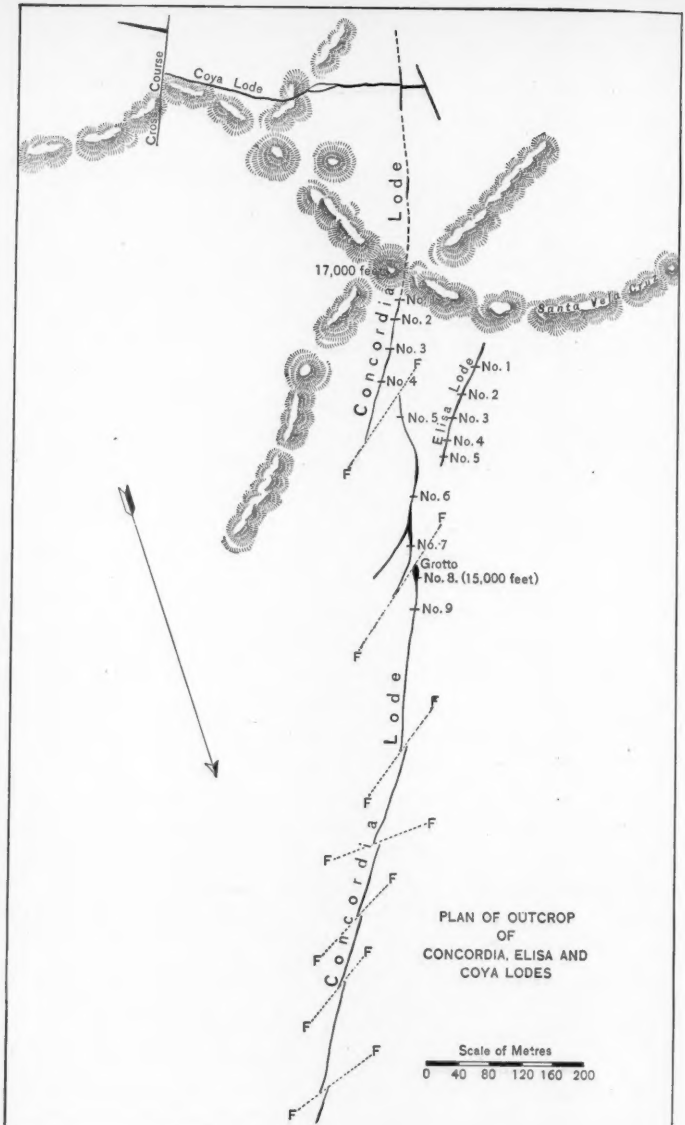

Cross Course
Coya Lode
Concordia Lode
17,000 feet
No. 1
No. 2
No. 3
No. 4
Santa Vara Mine
Elisa Lode
No. 1
No. 2
No. 3
No. 4
No. 5
No. 5
No. 6
No. 7
Grotto
No. 8. (15,000 feet)
No. 9
Concordia Lode
F
PLAN OF OUTCROP
OF
CONCORDIA, ELISA AND
COYA LODES
Scale of Metres
0 40 80 120 160 200

FIG. 35.

This granular quartzite is characteristic of the district, but, as a rule, it occurs in distinct beds having a definite strike. In the opinion of the writer the difference between this rock and the usual quartzite schist is due to action of mineralizers and is the result rather than the cause of the ore bodies.

The Concordia Lode.—The Concordia lode (see Fig. 35) strikes 10 degrees east of north and west of south, approximately following the strike of the country rock. Its dip is vertical. From Fig. 35, which is a plan reduced from the actual survey of the outcrop of the lode, it will be seen that it is subject to a number of dislocations; it is also subject to a great number of twists which are too small to be shown in Fig. 35; both the twists and dislocations are without exception "lefthand." The dislocations occur without any sign of cross course or intersecting fissure and it is questionable whether they represent fractures of the lode or no.

FIG. 36. Plan of the Tin-bearing granitic dyke occurring on the Mt. Eurowie Tin Mining Co's property, New South Wales. *After J. B. Jacquet Min. Res., N. S. Wales.*

In the "Mineral Resources of New South Wales," by Mr. Ed. Pitman (Sydney, 1901), page 147, there is an interesting description of a dyke also tin-bearing, which has similar interruptions. Mr. Pitman says: "At Eurowie the ore occurs in coarsely crystalline granite or greisen which intrudes metamorphic rock. . . . The granite dykes are variable in their dimensions, being usually one to twenty feet and occasionally one hundred feet in width, terminating abruptly with rounded ends. . . . Ten or fifteen short dykes may be arranged in the same general direction and nearly but not quite continuous, the posterior end of each being slightly to one side of, and overlapping the anterior end of its neighbour; so that the series when shown

in plan resembles a lode which has been intersected and heaved by a number of parallel cross courses. There are however no cross courses" (see Fig. 36).

It may be possible that the Concordia lode is an analogous case to the dyke at Eurowie, but the writer does not think that this is so. These interruptions are believed to be really dislocations of the same lode, because the many twists and bends—some nearly at right angles—lead one to suppose that it would not have required so very much more pressure to have converted the bends into dislocations without any sign of a cross course.

Further the brecciated character of the lode denotes a true fissure whose walls have undergone considerable movement and it is difficult to imagine such a succession of fissures so close together without their having originally been one and the same.

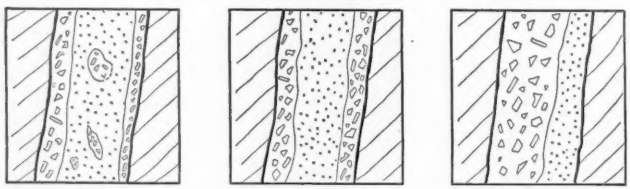


FIG. 37. Sections showing relation of Quartz Porphyry to Breccia in the Concordia Lode. Diagonal lines indicate wall rock (quartzite schist); dotted areas indicate quartz porphyry; brecciated areas indicate breccia filling.

Cassiterite and other minerals are nearly always found close to the faults and in the bends of the lode.

The lode sometimes pinches out completely for considerable distances; in one instance in the lowest working, it gradually tapered out and finally disappeared, but it was picked up again fifty feet further on. Where first regained it was one inch wide, but quickly widened out to its usual size.

The lode material is a breccia whose fragment are usually quite angular and consist chiefly of the quartzite schist. The cementing material is a mixture of quartz, tourmaline, cassiterite, zinc blende, iron pyrites, siderite and vivianite (sparingly).

Quartz porphyry also occurs in the fissure, sometimes side by side with the breccia, sometimes with breccia on either side of it and sometimes occupying the whole fissure from wall to wall (see Fig. 37). The quartz porphyry occasionally envelops fragments of the breccia but in no single instance did a piece of the true quartz porphyry form part of the breccia, a definite proof that the porphyry is later than the breccia.

The quartz porphyry is of fairly uniform type, groundmass finely felsitic, phenocrysts of large grains of quartz and occasional pseudomorphs of cassiterite and other minerals after mica and feldspar, and often small quantities of cassiterite disseminated through the rock in fine grains.

The breccia varies considerably in the different levels, its component fragments differing in size from pieces as small as a pin's head to rocks weighing half a ton.

There is a considerable variation in the cementing material, the various accessory minerals (quartz and tourmaline forming the base) occurring by no means regularly. Also there are, in the cement, some exceedingly interesting segregations of quartz and feldspar. These occur as rounded aggregates from one inch to six inches in diameter, and at first sight may be mistaken for the quartz porphyry, but under the microscope they are seen to be holocrystalline and to consist of fairly large crystals of quartz and felspar with muscovite, the felspar much decomposed; frequently these segregations are rich in cassiterite, zinc blende and pyrites; they remind one immediately of a pegmatite.

The cementing solutions or emanations have often corroded the fragments of breccia and in some places a complete replacement of quartzite by cassiterite is found.

On specimen obtained by the writer is eight inches square by two inches thick and resembles merely an ordinary piece of iron-stained quartzite schist, having the usual bedding and cleavage planes, but when broken proves to be practically solid cassiterite.

The most interesting part of the lode, both from an economic

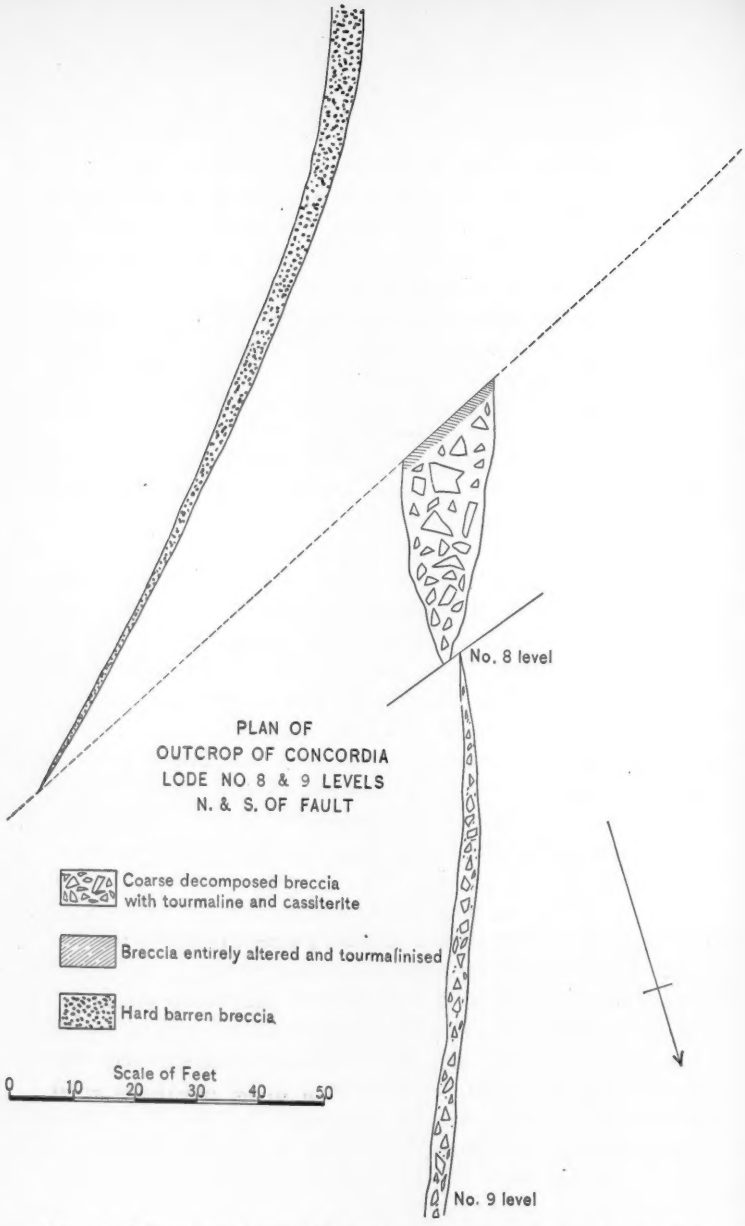


FIG. 38. Plan of the Concordia Lode No. 8 and 9 levels N. and S. of fault.

and geological point of view, occurs in levels nos. 8 and 9 and in an old working above no. 8 called "The Grotto" about 1,000 feet from the top of the mountain.

Fig. 38 shows a plan of the outcrop and Fig. 39 a longitudinal section from the grotto to no. 9 level. The plan shows the lode coming in from the north with its usual width (three feet), a small fault with left-hand heave of two feet, then a lode, four inches wide, with a cement of rich cassiterite and chalybite,[1] gradually opening up into a pocket fourteen feet wide of coarse breccia with oxide of iron, pyrites and tourmaline, carrying an average of seven per cent. cassiterite, then a fault with a left-hand heave of thirty feet and a narrow lode with a compact, hard, barren breccia, gradually widening to the average width of three feet.

In the grotto from the fault northwards the lode shows a great alteration for three feet, the quartzite of the breccia being converted into a green mass of tourmaline and quartz, the rock however still retaining the original schistose structure of the quartzite. In some cases pieces of the breccia show a core of unaltered quartzite. In no. 8 level, at the fault, this alteration does not occur, but in a winze sunk from no. 8 to no. 9, following the fault plane, the tourmalinization is very distinct, widening out until the entire pocket is simply a mass of green altered quartzite; the cement here is hardly visible, but can be traced occasionally by cassiterite crystals. In no. 9 level the mass of altered breccia extends back from the fault a distance of fifteen feet, gradually changing to a soft lode in which the breccia is represented by clay, oxide of iron and a considerable percentage of cassiterite; in this level the quartzite country rock is altered to a white clay for two feet on either side of the lode.

In no. 9 level two dykes of quartz porphyry were encountered as shown in the longitudinal section (Fig. 39); and in the winze, which was continued, the pocket pinched out, the soft tourmalinized lode fourteen feet wide giving way to a narrow lode of hard breccia, very much mixed up with, and hardly to be distinguished from, the country rock.

[1] Siderite.

The rest of the mine shows a lode with an average width of three feet, occasionally widening out into pockets and a more or less uniform breccia with a varying cementing matter, the foundation of the latter being always quartz and tourmaline. The quartz-porphyry outcrops in the fissure at various places.

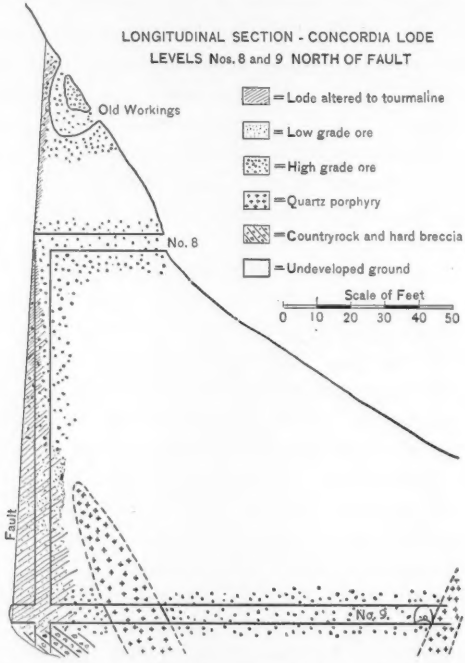


FIG. 39. Longitudinal Section, Concordia Lode levels 8 and 9 north of fault. Shows quartz-porphyry dykes and alteration to tourmaline rock in neighborhood of the fault.

Deductions.—From the above data the writer ventures to draw the following conclusions:

That the fissure was formed at the time, or soon after the general upheaval of the Andes, the dislocations followed and then the quartz porphyry intruded, stretching up from the hearth

below in a series of finger-like dykes and following in the fissure a line of weakness. As the quartz porphyry was cooling, emanations or aqueous magmas were formed more siliceous than the original rock and saturated with metals, tin, zinc and iron combined with boron and sulphur; these solutions or vapors, finding their way up into the interstices of the breccia, eventually formed the cementing material of the lode and occasionally perhaps,

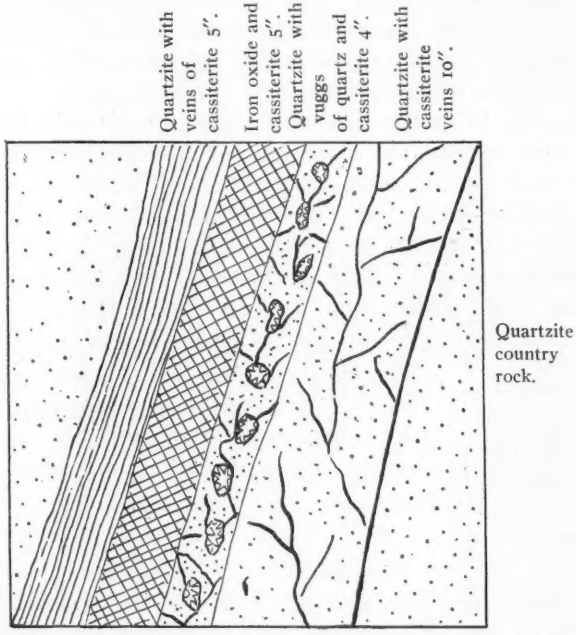

Quartzite with veins of cassiterite 5".
Iron oxide and cassiterite 5".
Quartzite with vuggs of quartz and cassiterite 4".
Quartzite with cassiterite veins 10".
Quartzite country rock.

FIG. 40. Cross section of the Elisa Lode. Showing relation of country rock and vein matter.

finding available space and suitable conditions, some of the magma would crystallize out into the pegmatitic segregations of quartz and felspar alluded to above.

The Elisa Lode.—This lode, also of the Concordia mine,

strikes a little more east of north and west of south than the Concordia lode and looks as though it might intersect the latter at the "grotto," though in point of fact the intersection of the two lodes has not yet been located with any degree of certainty.

The Elisa lode is tin-bearing where it passes through one of the belts of white granular quartzite which have been described above. These belts have no distinct relation to the strike of the schists and seem to be due rather to the effect of the mineralizers than to have been the cause of the deposition of cassiterite; generally they are full of small pockets and veinlets of tourmaline and cassiterite with secondary quartz.

The Elisa lode proper consists of a band of oxide of iron about twelve inches wide, but where the conditions are favorable the lode contains several bands, and sometimes pay values will extend into the quartzite on both sides without any definite walls, the latter even at their best being badly defined. Fig. 40 illustrates the development of the Elisa lode under the most favorable conditions. Thin sections from this lode show both the ore and the quartzite to be saturated with tourmaline, needles of this mineral penetrating both cassiterite and quartz. There is little question that this deposit is due to the same cause as the Concordia lode, namely the after actions of the intruded quartz porphyry.

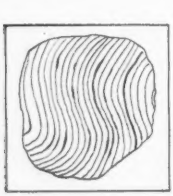


FIG. 41. Schistose structure in specimen of Stanniferous Quartzite from Monte Blanco Mine.

THE COYA MINE.

This mine adjoins the Concordia and has the same quartzite schist for its country rock. The principal lode strikes east and west and is called the "Coya lode" and intersects the Concordia lode as shown in Fig. 35; it is a mixture of white granular quartzite with quartz and oxides of iron and tin and dips 70 degrees to the south-southwest.

Tourmaline is associated with the cassiterite and is found abun-

dantly in the little seams and veins which traverse the lode. A boss of quartz porphyry outcrops close to the lode and the latter is also intersected in several places by dykes of the same rock. Here again the only reasonable theory for the deposition of the tourmaline-cassiterite vein is that of the after actions of the eruptive rock.

MONTE BLANCO MINE.

This mine, situated fifteen miles northwest of Concordia, is in the center of the Tres Cruces district and the same quartzite schists continue through. The distinguishing feature of the mine is a remarkable series of quartzite-cassiterite schists, which, though in some degree resembling the quartzite belts of the Concordia mine, are true beds with a definite strike and can be traced for considerable distances.

The ridge on which the mine is situated runs northeast and southwest, and the beds of quartzite cross the ridge at right angles, having a general strike of northwest and southeast.

There are three large belts of stanniferous quartzite from thirty to forty feet wide with a generally very well-marked schistose structure—cassiterite and tourmaline occurring between the laminæ. Sometimes, however, the quartzite is more massive, the ore being found in bunches and veinlets.

Fig. 41 is a sketch of a hand specimen from one of the Monte Blanco belts which shows the schistose structure particularly well.

The beds, where stanniferous, average between 0.5 and 0.25 per cent. tin oxide and are bounded by beds of a much darker color and much more slaty character. No outcrop of igneous rock can be observed on the ridge itself, but quartz porphyry and granite occur in the vicinity.

Tourmaline is abundant, being associated with the cassiterite in all the laminæ and veins throughout the quartzite.

There are lodes also in the mine, some rich in tin. They are generally brecciated and carry at the outcrop considerable quantities of iron oxide.

It seems pretty certain that the tin and tourmaline must have been deposited in the quartzite schist from solutions or vapors

emanating from the neighboring eruptive rocks at the time of their solidification.

BARROSA COTA MINE.

This mine, some three miles southeast from Monte Blanco, is still in the same geological country and the rock is still quartzite schist.

No quartzite cassiterite belts were observed in this mine. The tin is found in rather pyritic lodes associated with tourmaline and magnetic iron.

The main lode is well defined with a white quartz leader and streaks and pockets of tin. Some very pretty specimens of the so-called "wood tin" have been found.

There is also an interesting outcrop of a quartz-tourmaline dyke, which in thin sections shows moderate sized quartz crystals penetrated in all directions by masses of tourmaline needles. Quartz porphyry occurs in the neighborhood, and a similar origin may be ascribed to these deposits as to those of Concordia and Monte Blanco.

SAN ROQUE MINE.

On the southwest slopes of Santa Vela Cruz, in the valley of Sayaquiera, is situated a small group of mines, the principal of which are "San Roque" and "La Boliviana." These mines are working a lode named the "Gallofa" or its branches. The country rock is the usual quartzite schist, which at this point strikes east and west and dips to the north at an angle of 50 degrees.

The "Gallofa" lode also strikes east and west, but dips to the south at an angle of 76 degrees. It is well defined, with good walls and averages ten feet in width, but all the values are carried by the two feet next to the hanging wall. The gangue is decomposed quartzite, oxide of iron, iron pyrites, arsenical pyrites, chlorite and tourmaline.

In the mine itself no igneous rock is to be seen, but there are large masses and dykes of a porphyritic rock in the neighborhood of the types (*k*) and (*l*), and with the presence of abundant tourmaline. The origin of these deposits may be ascribed to the

same causes which have produced the other tin mines of the district.

NOTES ON THE MICROSCOPICAL CHARACTER OF THE ROCKS FROM TRES CRUCES.

In March, 1905, at the request of Mr. Arthur Pearce, then manager of the Andes Tin Company, Mr. Charles P. Berkey, of Columbia University, made a microscopical determination of some of the tin-bearing rocks from Concordia mine.

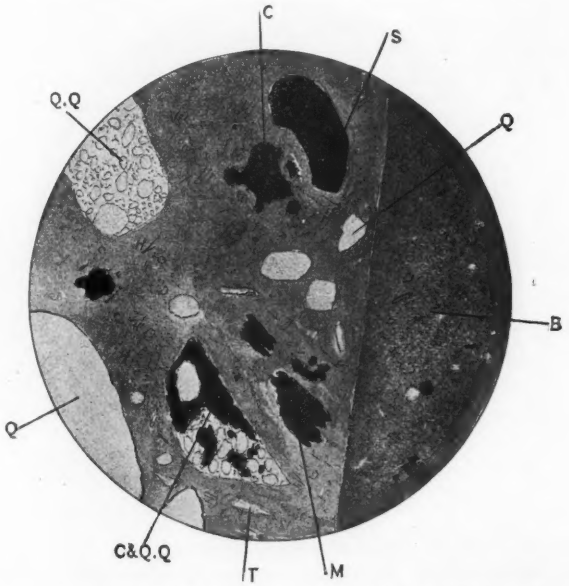


FIG. 42. Type (*a*). × 28 Diameters. Crossed Nicols. Concordia Breccia. *B* = part of fragment of quartzite schist. Rest of section is cementing material as follows: *Q* = Quartz. *Q.Q* = Quartz aggregates. *C* = Cassiterite. *S* = Sulphide. *M* = Biotite Mica. *T* = Tourmaline. Groundmass = Quartz and Tourmaline.

Lately the writer has also examined some of the Tres Cruces rocks under the microscope and ventures to combine his notes with those of Mr. Berkey, trusting that he will accept this acknowledgment.

Mr. Berkey writes as follows as an introduction: "The rocks involved are:

"1. Country rock, which is of all grades from a true quartzite to a quartz schist. As a type for use as a general term, covering all facies of it, I have called it in these notes a quartzite schist.

"2. Breccia, which is a fault or friction breccia, whose fragments are usually quite angular and made up, chiefly at least, of the above described quartzite schist.

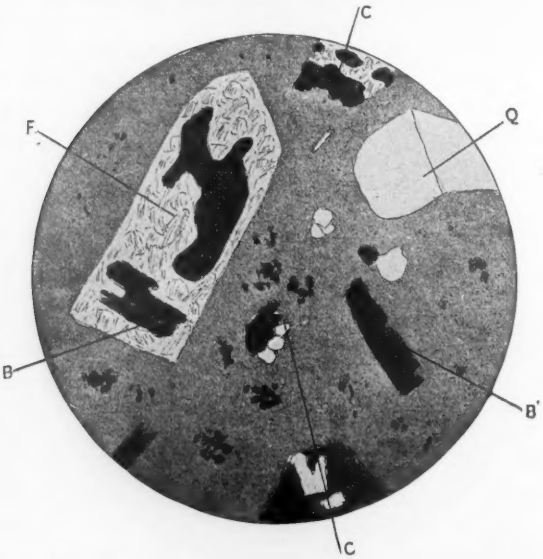


FIG. 43. Type (*b*). × 28 Diameters. Crossed Nicols. Quartz porphyry from Concordia Lode. Felsitic Groundmass. *F* = Phenocryst of Feldspar altered to muscovite. *B* = Biotite altered to cassiterite. *C* = Cassiterite. *Q* = Quartz.

"The cement of this breccia is, in its present condition, a mixture of quartz, tourmaline and cassiterite with very little other matter in most parts. The brown drab color is given chiefly by the tourmaline, which is abundant.

"3. Quartz porphyry, which is a true quartz porphyry of fairly uniform type. As to secondary changes there is some difference

in the specimens; in one there is much cassiterite in pseudomorphous growth after certain of the phenocrysts, especially after mica and apparently also after felspar."

The association of minerals in the whole series is in support of the presence of mineralizers in connection with igneous intrusion and contact phenomena. In many places the cement of the breccia resembles much the ordinary quartz porphyry of the regular

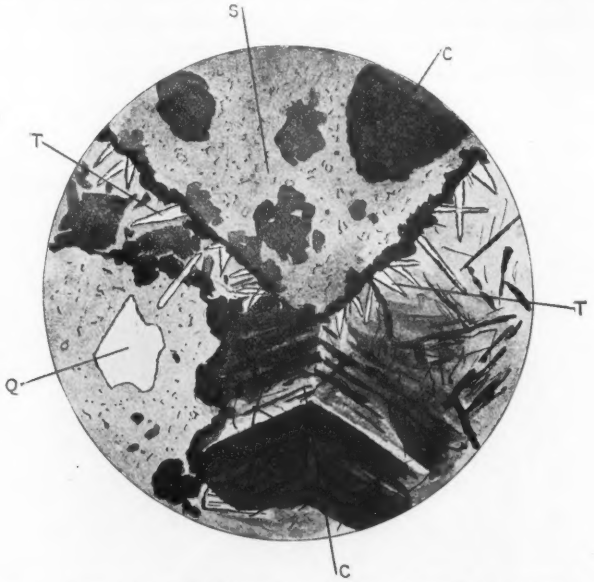


FIG. 44. Type (*c*). × 28 Diameters. Analyser Removed. Another specimen of Concordia Breccia. *S* = Quartzite Schist. Balance of section is cementing material as follows: *C* = Cassiterite. *Q* = Quartz. *T* = Tourmaline.

specimens except for its extreme saturation with tourmaline. It may easily be a modification of the porphyry magma in large part. Mr. Berkey continues describing the various thin sections in detail. The following have been selected as typical:

Fig. 42 (*a*). Concordia breccia. Mr. Berkey writes: "In this breccia the fragments are the usual country rock, viz. a quartzite schist

cemented by a drab colored mixture of: Quartz grains (large), fragments of an aggregate of quartz grains, cassiterite, biotite, tourmaline, sulphides. The matrix of the breccia is strongly suggestive of the structure of the quartz porphyries except for its abundant tourmaline. The large grains remind one at once of the phenocrysts in the porphyry. Besides these there are other areas of secondary products that seem to preserve the structure of original feldspar and mica and it is in these areas that most of the tin is developed. Can this be a facies of the porphyry magma?"

Fig. 43 (*b*). From Concordia lode. Mr. Berkey says: "A quartz porphyry. The groundmass finely felsitic, the phenocrysts are

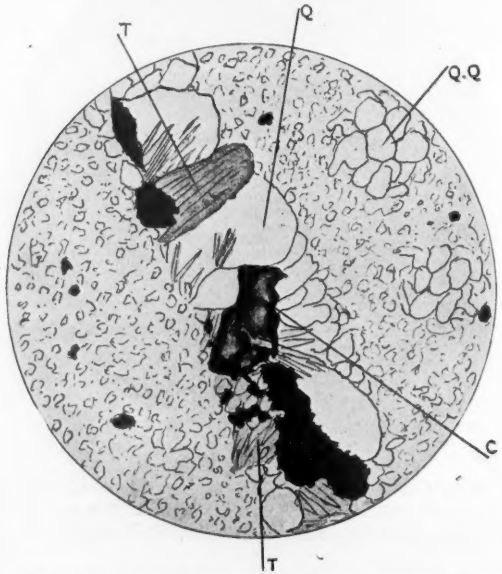


FIG. 45. Type (*d*). × 28 Diameters. Analyser Removed. Quartzite with disseminated Cassiterite and cut by small veins. *C* = Cassiterite. *T* = Tourmaline. *Q* = Quartz. *Q.Q* = Quartz aggregates.

abundant and represent: Quartz in fine large crystal grains that show marked resorption phenomena; in this specimen however the phenocrysts are in part replaced by secondary quartz and cassiterite,

i. e., pseudomorphs. The cassiterite has entirely filled the smaller spaces once occupied by mica and also some of its feldspars are replaced by cassiterite. There is secondary quartz and muscovite. Cassiterite is abundant in this rock as a pseudomorph."

Fig. 44 (*c*). From Concordia lode. Mr. Berkey says: "There is no difference between this and (*a*) except the cassiterite is in very large grains and crystals, showing zonal structure, twinning and some crystal faces. Clear tourmaline crystals penetrate both the cassiterite and secondary quartz. The matrix as usual is largely tourmaline."

Fig. 45 (*d*). From Elisa lode. The groundmass is quartzite, the component quartz grains being larger than usual. The quartzite is traversed by a vein composed of large quartz crystals, tourmaline and cassiterite. There are also small grains of cassiterite disseminated through the quartzite.

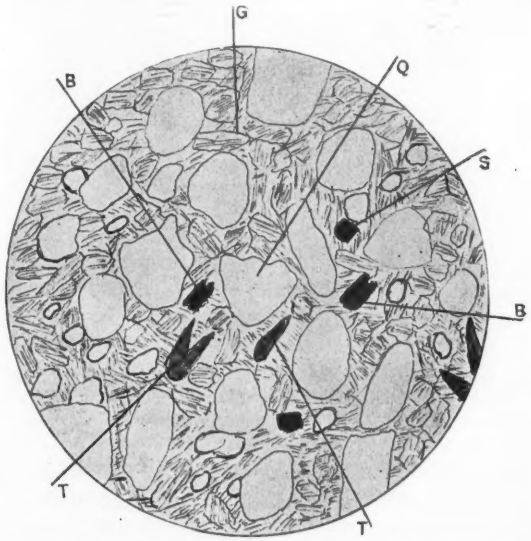


FIG. 46. Type (*e*). ×28 Diameters. Analyser Removed. Mineralized country rock (Quartzite Schist) from Concordia Lode. *G* = Groundmass of muscovite and biotite. *T* = Tourmaline. *B* = Biotite. *Q* = Quartz. *S* = Sulphide.

Fig. 46 (*e*). Country rock, Concordia. Mr. Berkey writes: "The usual quartzite schist, rather coarser than the average country rock specimens; but in addition to the regular constituents in this slide, there are developed to a limited extent the minerals characteristic of the breccia cement, namely: Tourmaline, cassiterite (doubtful), sulphides."

Fig. 47 (*f*). Branch lode, Concordia. Mr. Berkey writes: "A rather decayed looking hand specimen, but in thin section the rock

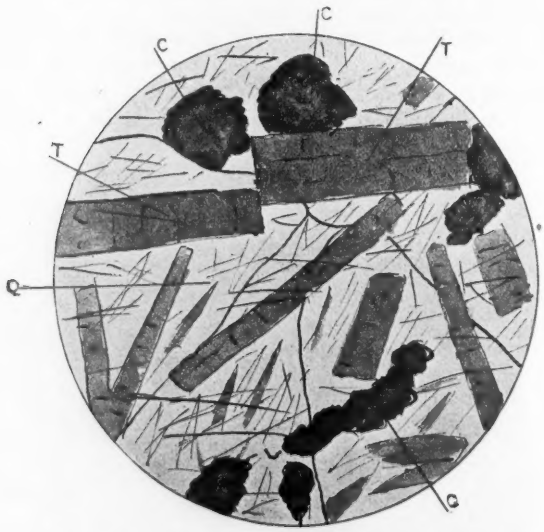


FIG. 47. Type (*f*). ×28 Diameters. Analyser Removed. Ore from Branch Lode, Concordia Mine. *Q* = Quartz penetrated by tourmaline needles. *C* = Cassiterite. *T* = Tourmaline.

shows splendidly the ore association. All the constituents are developed to large size. There are many long crystals of drab-colored tourmaline penetrating crystalline vein quartz and associated with crystals and grains of cassiterite."

Fig. 48 (*g*). From the Concordia lode. Cut from one of the interesting segregations in the breccia. Groundmass muscovite mica with phenocrysts of large quartz crystals and decomposition prod-

ucts of mica and felspar. It may be considered a connecting link between the cement of the breccia and the quartz porphyry.

Fig. 49 (*h*). From Barrosa Cota. Quartz tourmaline rock. Consists of quartz crystals penetrated by a mass of tourmaline needles,

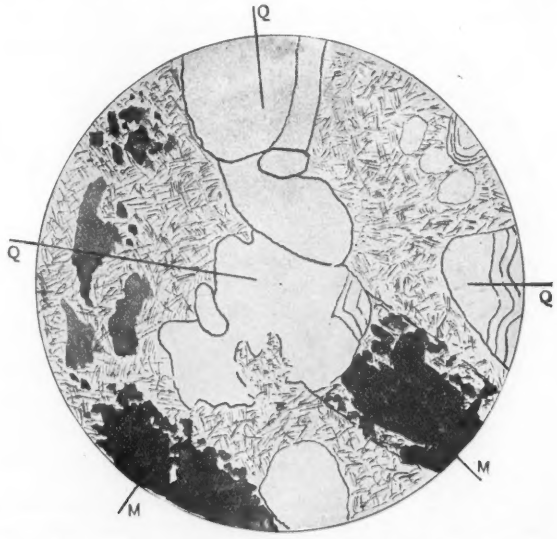


FIG. 48. Type (*g*). × 28 Diameters. Crossed Nicols. Seggregation in Breccia of Concordia Lode. Transition type between Cement of Breccia and Quartz porphyry. Groundmass = Muscovite Mica. *Q* = Quartz. *M* = Decomposition products of mica and feldspar.

the latter being in some cases so thick as to entirely replace the quartz.

Fig. 50 (*i*). From the Coya lode. Groundmass a coarse quartzite with tourmaline and a little cassiterite, penetrated by veins of tourmaline and cassiterite, the latter in well-formed crystals.

Fig. 51 (*j*). From the Monte Blanco quartzite belt. Very similar to Fig. 50 (*i*) but here the tourmaline and cassiterite occur between the foliæ of the schist.

Fig. 52 (*k*). From the Mariana mine, Tres Cruces. A porphyritic rock with a felsitic groundmass. The phenocrysts are: Orthoclase felspar, quartz, biotite. The felspar is often altered to muscovite.

Fig. 53 (*l*). From Guariananta, Tres Cruces. A porphyritic rock with groundmass chiefly quartz. The phenocrysts are: Quartz, plagioclase with twin lammellation, biotite, bunches and nests of tourmaline.

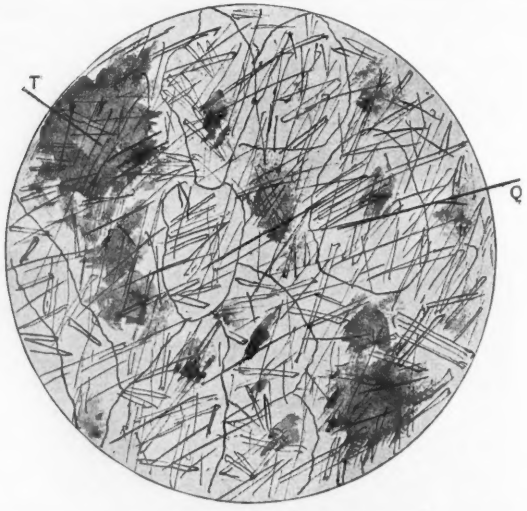


FIG. 49. Type (*h*). × 28 Diameters. Crossed Nicols. Quartz-tourmaline rock from Barrosa Cota. *Q* = Quartz penetrated by tourmaline needles. *T* = Tourmaline.

THE ORURO TIN FIELD.

To the southeast of Oruro lies a huge flow of andesite (Fig. 57, type *N*), covering an area of at least 500 square miles, but whose exact dimensions it has not been possible to ascertain up to date; the nearest outcrop to Oruro is at Negro Pabellon (see Plate V) from where it passes east of Huanuni and north of Llallagua and to the south of Berenguela. Its boundary to the south is not known to the writer. The character of the andesite appears fairly uniform over this large area. It is a mica andesite carrying in some places a good deal of magnetite; it is not intrusive, but covers up the older rocks and is probably of comparatively recent date.

Most of the mines of the Oruro district are situated close to the edge of this flow, but never, as far as the writer is aware, do the lodes penetrate the andesite, but are connected in time and probably also in origin with quartz porphyries of older date.

The fact that the majority of the mines are situated close to this junction of the andesite with the quartzite rocks is probably merely a coincidence and there are probably many valuable

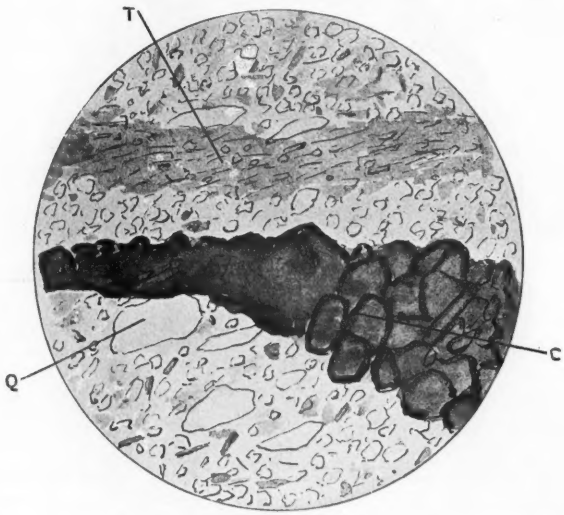


FIG. 50. Type (*i*). × 28 Diameters. Crossed Nicols. Ore from Coya Lode. Groundmass = Quartzite with Tourmaline. *C* = Cassiterite. *Q* = Quartz. *T* = Tourmaline.

tin deposits covered up by this lava flow. The tin deposits are regarded by the writer as due entirely to the older igneous rocks.

Possibly the heat and energy generated by the andesite and by its causes may have exercised some effect on the later mineral deposition but it would presumably have been very small and in nowise have affected the tin contents. Should, of course, a tin lode be found in the andesite, its occurrence would entirely upset this theory, but up to date no such deposit has been discovered.

NEGRO PABELLON.

The tin mines of Negro Pabellon lie twenty miles east of Oruro. To the north and east of the mines lies the andesite, to the south and west is quartzite schist. It is in the latter rock that the tin deposits are found.

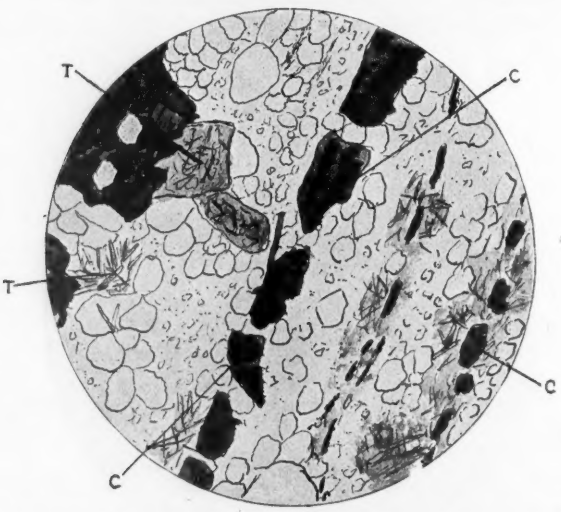


FIG. 51. Type (*j*). × 28 Diameters. Crossed Nicols. Mineralized Quartzite Schist ore from Monte Blanco Mine. Groundmass = coarse quartzite with tourmaline and cassiterite in the laminæ. *C* = Cassiterite. *T* = Tourmaline.

The quartzite beds strike N. 30° W. and S. 30° E. and dip about 30° S. 60° W.

One of the most interesting deposits and the only one of this group which will be described is called "La Unificada." It is what the Bolivian miner calls a "manto," which means a more horizontal deposit or flat lode as opposed to a vertical one. The mine is situated on the top of a ridge between two peaks, the latter being called Negro Pabellon and San Pablo respectively (see Fig. 54). Negro Pabellon is andesite and San Pablo is

quartz porphyry, the tin deposit being in the quartzite schist lying between the two volcanic rocks.

The quartzite schist is of the usual type, but much seamed by veins of quartz. The quartz porphyry is described in the microscopic notes (Figs. 56 *M* and 58 *O*), but is of an extremely variable type. In some places the phenocrysts are crystals of orthoclase felspar, two inches long. In others the felspar is plagioclase and in small crystals, while the quartz crystals are developed to large size, and occasionally the felspar is entirely replaced by radiating aggregates of tourmaline.

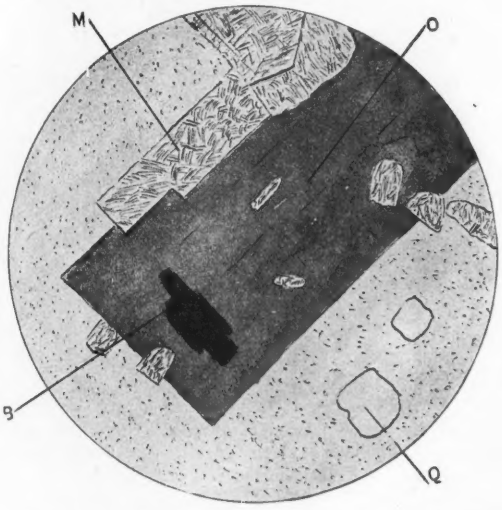


FIG. 52. Type (*k*). × 28 Diameters. Crossed Nicols. Quartz-porphyry from Mariana Mine, Tres Cruces. Groundmass felsitic. *O* = Orthoclase. *M* = Feldspar altered to muscovite. *B* = Biotite. *Q* = Quartz.

In the quartz porphyry, close to the boundary of the quartzite schist occurs an outcrop of breccia, almost precisely similar to that of the Concordia lode, with a dark blue cement consisting chiefly of tourmaline. This breccia had not been worked for tin, neither was any cassiterite detected in it.

The top of the ridge is very much weathered and the rocks are decomposed for a depth of thirty feet. The outcrop of the "manto" cannot be seen.

In the mine the manto appears as a flat lode with a dip of 18° to S.E. and getting steeper in depth. Along the strike it is cut

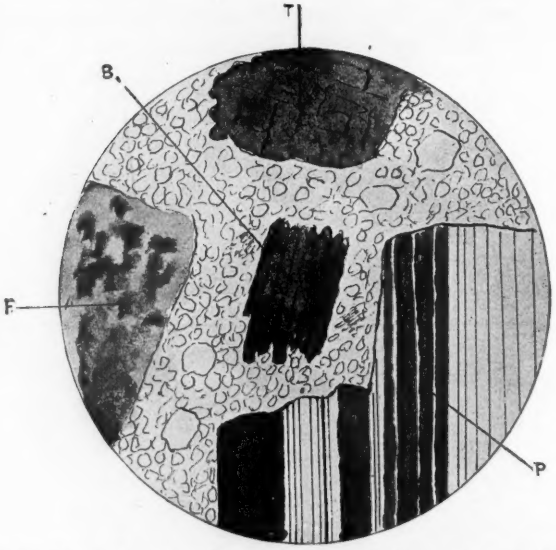
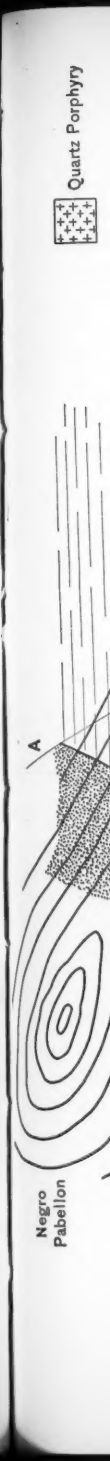


FIG. 53. Type (*l*). × 28 Diameters. Crossed Nicols. Porphyritic rock from Guariananta. Groundmass chiefly quartz. *T* = Tourmaline. *B* = Biotite. *P* = Plagioclase. *F* = Decomposed feldspar.

off on one side by a dike of quartz porphyry and on the other by quartzite, therefore showing an ore body about 100 feet wide dipping into the ridge. The average thickness is three and one-half feet and a section through the deposit is shown in Fig. 55.

The hanging wall or roof is composed of quartz, sometimes carrying a little tin, then a yellow sandy bed, looking almost like a soft sedimentary sandstone, about two inches thick and rich in tin. Underneath this follows a chocolate-colored bed,



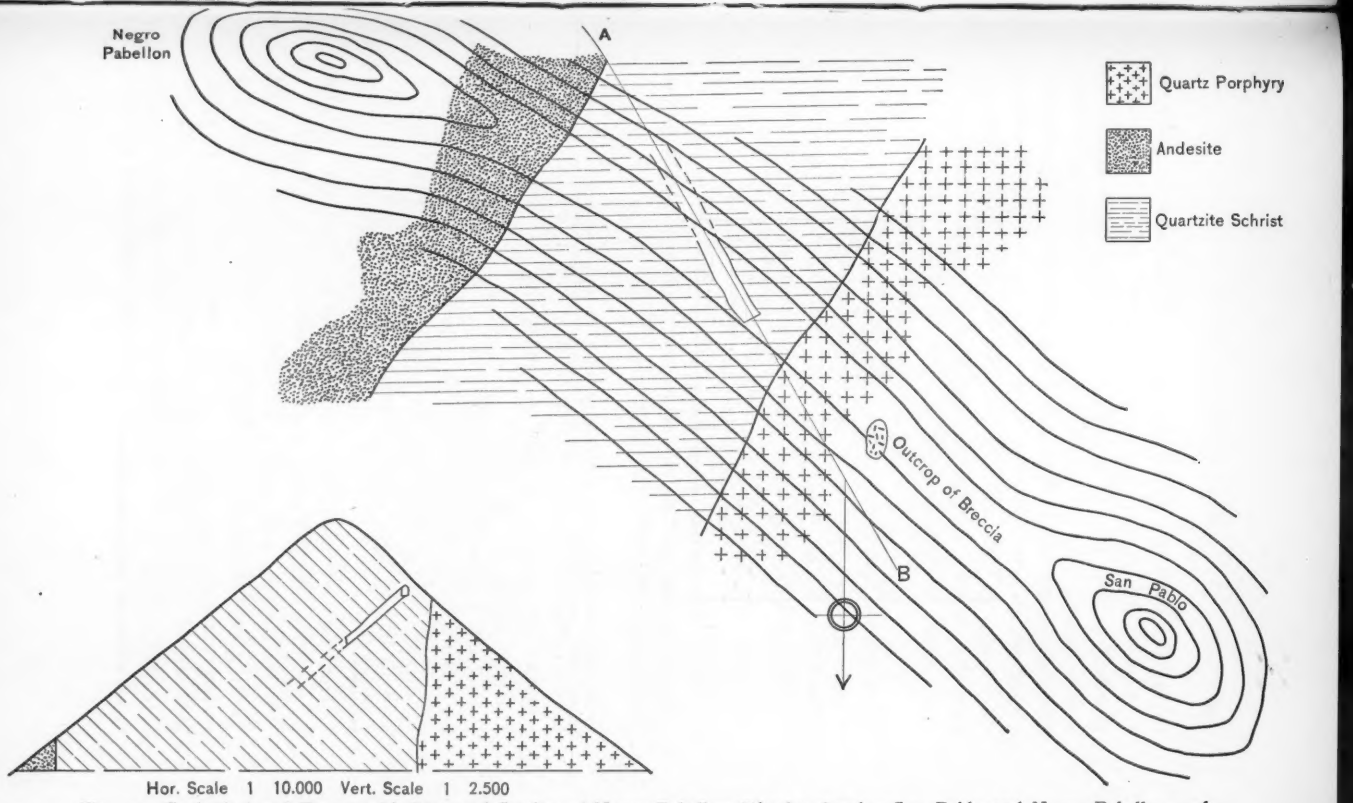


FIG. 54. Geological and Topographic Map and Section of Negro Pabellon District showing San Pablo and Negro Pabellon peaks.

carrying a good deal of iron oxide, a little sand and a small percentage of tin, passing into a heavy dense band of iron oxide, generally poor in tin. The footwall or floor is clay with angular quartz passing into decomposed quartzite. No tourmaline was observed in the ore body, neither did the only thin section cut

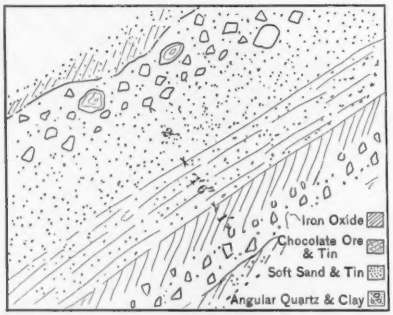


FIG. 55. Section of "manto" or flat vein in Negro Pabellon district showing nature of the tin ore and enclosing rocks.

from the chocolate ore show anything except oxide of iron apparently deposited in layers from solution and a few tin crystals scattered through it, similar in appearance to the ore from Huanuni shown in Fig. 60 *Q*.

Probably a more exhaustive examination would show the presence of the boron mineral, as it certainly occurs quite plentifully in the surrounding rocks, but the writer confesses at the time of visit to having been more concerned with tin than with tourmaline.

The origin of this interesting deposit is not clear and will not be, until considerably more work has been done in the mine.

Is the deposit, with such a well-defined banded structure and showing such evidences of having been the path of an important underground channel, merely 100 feet wide? Or is there a flat lode with a much greater length of strike and is our "manto" a faulted portion of it? Again, is this a case of "precipitation from mineral springs" or not? Certainly the deposit was not

produced simultaneously with precious silver ores and sulphides of Cu, Fe, Pb and Zn, for the only mineral there besides oxide of iron, quartz and cassiterite was barytes, and this only in one level in the mine.

If the "manto" is the product of a mineral spring, the writer considers this spring to have been most certainly fed by vapors or superheated water derived from the surrounding quartz porphyries and carrying tin, boron and iron in solution. It may be stated here that the porphyritic rocks of San Pablo carry small veins and pockets of wolfram.

The other mines of the district are usually well-defined lodes, but their ore often contains streaks of similar appearance to the chocolate ore of the Unificada. They are all in the same quartzite beds, in which the San Pablo quartz porphyries are intrusive.

THE HUANUNI GROUP.

About thirty miles southeast of Oruro lies the famous hill of Posoconi, through which hill runs the Cataricagua lode, forming one of the richest tin deposits in Bolivia. It was worked long ago by the Spaniards.

This group of mines is generally called Huanuni, the name of the mining village at the foot of the hill.

The geology of the district is practically the same as that of Negro Pabellon; quartzite schist and quartz porphyry covered in some places by andesite; the andesite passes to the northeast and the lode itself lies in quartzite of the usual type, while to the north occurs a big outcrop of dacite (see Fig. 61 *R*), which may be referred to the same age as the andesite and which contains no tin lodes. Intruding the quartzite schist are various dikes and masses of quartz porphyry. The Cataricagua lode strikes approximately north and south and dips east at a variable angle, apparently getting steeper in depth. The average dip is probably about 60 degrees.

The lode is a breccia whose cementing material is oxide of iron and the fragments are chiefly quartzite and quartzite schist. The cassiterite in the only slide, cut from the lode (see Fig. 60 *Q*),

appears as crystals scattered through the cementing material and, as far as could be determined from this one specimen, does not form part of the true cementing material but is later than the oxide of iron. This view of course might be entirely changed by a more exhaustive examination of the lode matter.

In this thin section no tourmaline was observed, but there is no doubt that more slide cutting would reveal the presence of this mineral. The lode is very strong and can be followed both on the surface and underground from one side of the hill to the other, in fact two distinct mining companies are working on the lode on opposite sides of the hill. The walls are well defined and slickensides are common. The average width of the lode is three feet,

Up to the present time a very small amount of sulphides have been encountered and as a whole it may be taken as an ideal tin proposition. To absolutely state the origin of this deposit is difficult without more research work, but it seems probable that after the fissure was filled by the breccia and its cementing material of iron oxide, emanations carrying tin in some form were introduced into the fissure and that these emanations had their origin in the after-actions of the quartz porphyries of the district.

MOROCOCALA.

To the north of Huanuni lies a small group of mines of the above name, perhaps destined to become as important as their celebrated neighbor. The writer has only had the opportunity, up to date, to pay a flying visit to these mines, and does not intend to describe any of the deposits in detail. A most interesting point from a geological standpoint is that the small hill in which the mines are situated is an inlier of quartzite schist in andesite.

The andesite flow occupies the high tableland for many miles on all sides, but fortunately for the owners, the Morococala hill has either been denuded of its lava cap or perhaps has never been covered. It is worthy of note that the native freeman had quite recognized the point, for when, in course of conversation, he

was asked if he had ever found any of the lodes penetrating the andesite, he replied that the "white rock" was only a crust and that it was no good looking for "metal" in it.

He was a better geologist than his manager.

THE PAZNA GROUP.

The mines of Antequera, Totoral and Avicaya lie some fifteen miles south of Huanuni and are situated on the north, west and east sides of the peak called "Chualla Grande." There are some half dozen or more lodes which are being worked at the present time, but as typical of the group the "Exaltacion" lode belonging to the Sociedad Estañifera de Totoral will be described. The extension of the Exaltacion has been worked also by Avicaya. The country rock is the usual quartzite schist and is intruded by dikes and masses of quartz porphyry.

Mr. Berkey, describing a thin section cut from the latter rock writes: "Large quartz phenocrysts are prominent. Abundant phenocrysts of some dark mineral, presumably biotite, are now altered to an aggregate of radiating tourmaline needles forming a most remarkable set of pseudomorphous areas. Some secondary quartz is penetrated by these needles. The groundmass is holocrystalline but exceedingly fine and even grained" (see Fig 62 *S*).

The quartzite beds strike north and south and dip to the west at about 30°. The Exaltacion lode has a similar dip and strike. The lode itself is a very hard, dark gray or green quartzite, saturated with tourmaline. At the outcrop and at various places in depth a breccia is found, which varies in thickness from two inches to one foot. At the surface this breccia is particularly well developed and a section was cut from it (see Fig. 63 *T*).

The breccia contains angular pieces of cassiterite and quartzite with cassiterite, showing that the formation of the breccia in this case was later than the deposition of the tin in the quartzite. The width of the lode varies from two feet to twenty-five feet, and is regarded as an impregnation of the country rock rather than as a lode, although the breccia certainly indicates a

fissure of some kind. The true country rock is a white quartzite schist very much softer than the lode and the indurated character of the lode is probably due to the quartz, tourmaline, tin solutions from the quartz porphyry.

The walls appear at first sight to be well defined, but on stoping the lode it is often found that behind the apparent wall is lode stuff carrying payable values and then another wall. One can hardly help looking on these walls as merely the bedding planes of the original quartzite schist and the lode as that part of the impregnated rock that will pay to stope.

The lode cuts through a ridge and outcrops on both sides, tunnels being driven through from one side of the hill to the other on it. The core is very hard blue quartzite with iron pyrites, but the outer portions having been more exposed to the action of surface water are softer and more oxidized.

The only minerals besides tin and tourmaline are oxide of iron, iron pyrites and a small amount of copper pyrites. The neighboring mines of Antequera and Avicaya contain similar deposits which seem to be nearly all beds of quartzite impregnated with tin and tourmaline solutions, or at any rate small lodes whose mineralizers have impregnated their walls for a considerable distance on either side. There can hardly be any doubt that these deposits are due to highly siliceous emanations carrying tin and boron from the volcanic rocks of the neighborhood.

THE LLALLAGUA GROUP.

The mines of Llallagua and Uncia are situated thirty miles east of Huanuni and comprise the following important mining companies: Campañia Estaña de Llallagua, Compañia Minera Uncia and La Salvadora.

The core of the hill on which these properties are situated is a huge boss of quartz porphyry intruding the usual slate and quartzite schist, the lodes being practically confined to this rock. They are supposed to pinch out when they enter the slate, but this point could not be confirmed, as during the writer's visit all the workings observed were confined to the quartz porphyry.

The slate seemed to be more favorable to silver, of which there are several mines in the district.

The quartz porphyry is of the usual type and is traversed in all directions by veins large and small, all of which contain tourmaline and generally cassiterite. The latter is often present in very small quantities.

The strike of the main tin-bearing lodes is approximately northeast and southwest but is variable. Even in any one lode

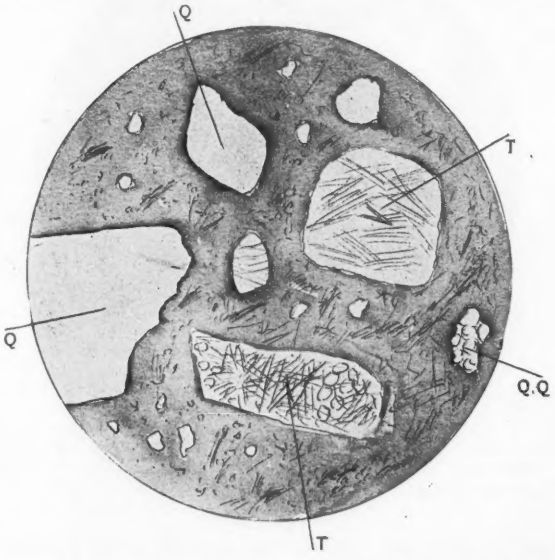


FIG. 56. Type *M*. ×28 Diameters. Crossed Nicols. San Pablo-Negro Pabellon Quartz-porphyry. *Q* = Quartz with inclusions. *T* = crystal of tourmaline. *M* = Biotite Mica altering into tourmaline. Groundmass = felsitic with some muscovite.

it may alter as much as 20° or 30°, many of the lodes being curved in a half moon. The faults are not numerous.

The walls are well defined and slickensides are common, but with one notable exception there is no impregnation of the walls by the tin-bearing solutions. The exception is the Bismarck

lode belonging to the Compañia Minera Uncia, where the width of the lode averages two feet, but where in some places the country is tin-bearing for three feet on either wall. Fig. 65 *V* is a drawing of a thin section cut from this impregnation.

The lodes nearly all dip at a steep angle, averaging 70°, to the

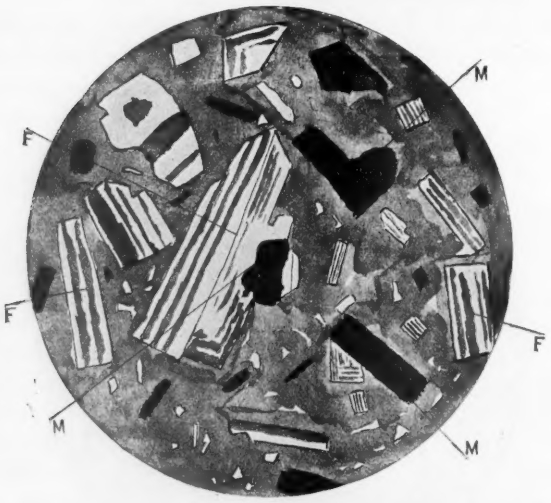


FIG. 57. Type *N*. × 28 Diameters. Crossed Nicols. Negro Pabellon Mica andesite. Groundmass = Glass. *M* = Mica altering to magnetite. *F* = Plagioclase feldspar.

northwest. They are narrow, the average width of the lodes which are worked at the present time not being over two feet; on the outcrop the gangue is generally oxide of iron, but in depth it passes into heavy sulphides containing often a considerable percentage of bismuth, a little silver and traces of gold, as well as antimony and arsenic.

The tin has been always present as oxide down to the present depth and never as stannite. One specimen, supposed to be sulphide of tin, proved on analysis to contain thirty-five per cent. bismuth, ten per cent. tin with sulphides of iron, antimony arsenic

and a trace of copper, the tin being present as oxide and the bismuth as sulphide. The long thin crystals of bismuthine had been mistaken for tin sulphide.

Nearly all the lodes pinch out and widen again both horizontally and vertically, due no doubt to movement of the walls.

None of the mines have reached any great depth at present, 200 meters or 656 feet being the deepest, and they form to-day the richest group of tin mines in Bolivia—perhaps in the world

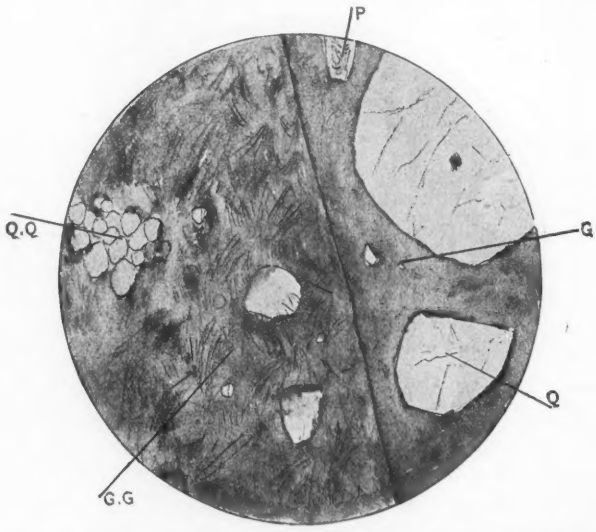


FIG. 58. Type *O*. × 28 Diameters. Crossed Nicols. Quartz-porphyry from Negro Pabellon. *G* = groundmass of porphyry-felsite. *G.G* = Pseudomorph probably after feldspar, groundmass tourmaline and secondary quartz. *Q.Q* = Secondary Quartz. *P* = Small pseudomorph probably after mica.

In the famous Llallagua mine, famous for its richness and notorious for its recent bad management at the hands of a Chilian company and Chilian managers, the writer saw in the bottom workings on the San José lode two meters of a soft iron oxide lode, which would probably average twenty per cent. tin.

In San Salvadora there is a dense sulphide lode averaging two feet in width and said to carry twenty-five per cent. tin and certainly carrying values in bismuth and silver.

The Compañia Minera Uncia is working an oxidized lode assaying from six per cent. to fifteen per cent. metallic tin over a milling width of 18 inches.

Riding from Huanuni to Llallagua one passes over the andesite sheet for several miles, in fact the Llallagua mine is only four or

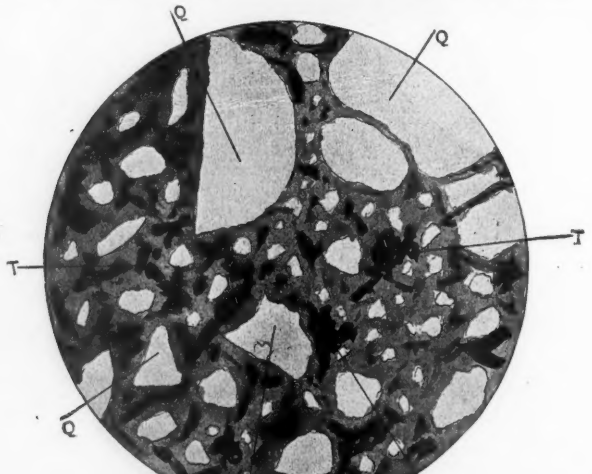


FIG. 59. Type *P*. × 28 Diameters. Analyser Removed. Quartz-tourmaline rock from Antequera. *Q* = Quartz. *T* = Tourmaline. Groundmass = tourmaline and quartz.

five miles outside the andesite, the latter rock being particularly well seen on the hills opposite Catavi (Llallagua mill site), where the andesite shows a rough columnar structure and where it is also seen to be a true lava covering up the ancient land surface.

As to the origin of the deposits, there can be no doubt that it must be attributed to the "after actions" of the quartz porphyry

boss. Although the lodes contain sulphide ores of bismuth, iron, silver and copper, the country rock, as well as the lodes, is so saturated with tourmaline that any other mode of origin would be a theory contrary to the established facts.

There is no evidence in the arrangement of the different minerals in the lodes to show that the various metals have been deposited at different epochs, in fact the cassiterite and the sulphides are so intimately mixed that one can only suppose they have been deposited simultaneously and there seems to be no reason why, if the "after actions" are responsible for the tin, they should not bear a similar responsibility for the sulphides.

CONCLUSIONS.

The above pages, it is hoped, will have proved fairly conclusively that the majority of the Bolivian tin deposits may be attributed to cause similar to those which have produced the other tin deposits of the world and which, as Dr. Stelzner says, have been willingly accepted as the exclusive method of tin occurrence.

We find then that the tin deposits of Bolivia are not in any way connected with the Cretaceous or Lower Tertiary andesites, but with quartz porphyries of a very much older date. Further, we find that the deposits are most distinctly characterized by the contemporaneous presence of minerals containing boron, tourmaline especially being most conspicuously present. Occasionally silver ores and sulphides of Cu, Pb, Fe, Zn are found associated with the tin ore, but, with the exception of silver, these minerals are common to all the tin deposits of the world, and, in no wise prove that the minerals were deposited from mineral springs. Up to date the writer believes that Bolivian tin has been looked upon with a certain amount of suspicion by tin consumers all over the world, but especially in the United States, and presumably this distrust has arisen from the belief that Bolivian tin deposits were such a complicated mixture of minerals that it was impossible to obtain clean enough concentrates to produce a good grade of tin in the smelter.

The writer remembers when he first received orders to proceed

to Bolivia. He read up every book to be found on the treatment of complex tin and silver ores, but it is to be feared however useful the information thus gained may be in other parts

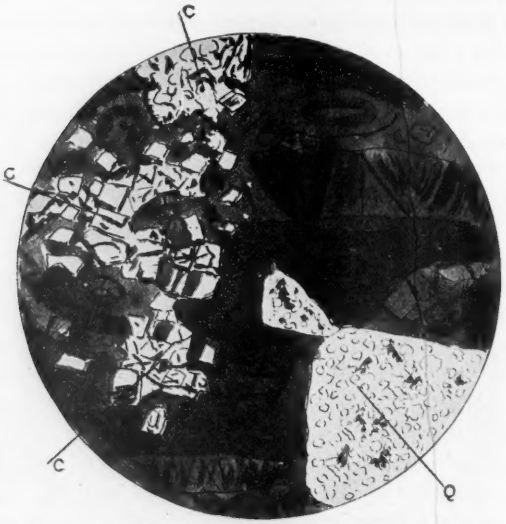


FIG. 60. Type *Q*. × 28 Diameters. Crossed Nicols. Huaununi Breccia from Cataricagua Lode. *C* = Cassiterite. *Q* = Quartzite rather decomposed. Cement = oxide of iron.

of the world, the time had better have been employed in studying Spanish.

It is true that the mines of Potosi and Oruro, silver mines worked since the time of the Spaniards, produce a little tin as well as silver, and that this tin is not of a very high grade, but all the big producers the writer has seen, have, or could have, if they knew the first principles of dressing, almost as clean a "barrilla" as the Straits and certainly cleaner than Cornwall.

FUTURE OF THE INDUSTRY.

Nearly all the tin mines in the Quimsa Cruz and Oruro districts are either in the hands of private owners or Chilian com-

panies, and it is to be feared that with few exceptions none of them know the first principles of mining development, tin dressing or even mining finance.

During the recent boom in Chile the mines changed hands at a price about ten times their value, on reports that if made in any other industry would land their authors in jail, and these mines have been placed in the charge of absolutely incompetent men,

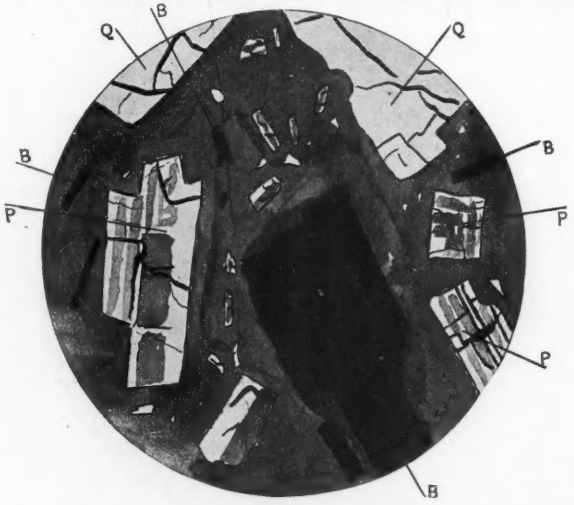


FIG. 61. Type *R*. × 28 Diameters. Crossed Nicols. Biotite Dacite from Huanuni. *B* = Biotite. *P* = Plagioclase. *Q* = Quartz. Groundmass = glass.

who as a rule have run the mine solely for their own and their friends' personal profit.

This Chilian boom sent prices up sky high and owners asked pounds sterling where they were only asking Bolivianos a year or two before. The prices asked to-day for tin mines in Bolivia are in the writer's opinion absolutely ridiculous, and it is difficult to see how foreign capital can come in on the present basis.

However the probable failure of the Chilian enterprises and

the drop in the price may bring the mine owners to their senses. Costs at present are very high, chiefly owing to mismanagement, lack of working capital and the hand-to-mouth system of mining. The cry is not How much ore can we develop this month? but, How much barrilla can we scrape out of the mine, regardless of cost or of the future of the mine. Owing to their position nearly all the mines could be very cheaply worked by means of adits, and yet the writer has seen the ore carried up on men's

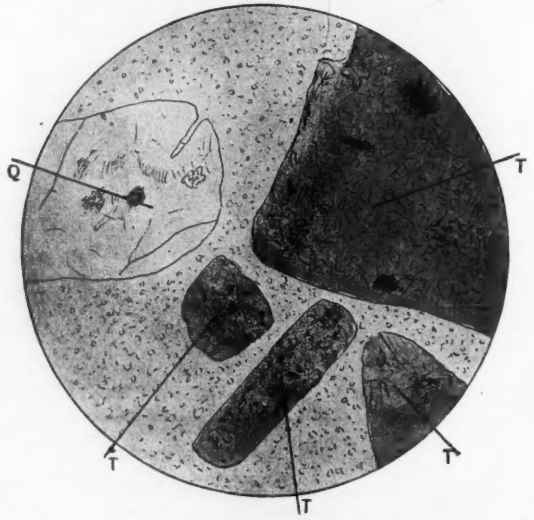


FIG. 62. Type *S*. × 28 Diameters. Analyser Removed. Porphyritic rock from Totoral. *T* = Phenocrysts of Biotite (?) now altered to radiating aggregates of tourmaline. *Q* = Quartz. Groundmass holocrystaline but very fine and even grained.

backs for hundreds of feet, where a few hundred of pounds spent properly would have brought it to the ropeway head in cars.

The cost of mining and milling varies widely under these conditions. At one of the best worked mines close to the railway the costs per ton of ore milled were £3–13–0 and at another having a reputation for economy the costs were no less than

£6–3–0 per ton of ore milled. Then in addition there must be added to this at least £25 per ton of barrilla for freight and smelting charges, etc.

One of our best engineers said the other day that he believed £2 per ton to be the lowest possible cost for mining and milling, but the writer does not think this figure has been approached yet.

We all hope that the proposed new railway system now under

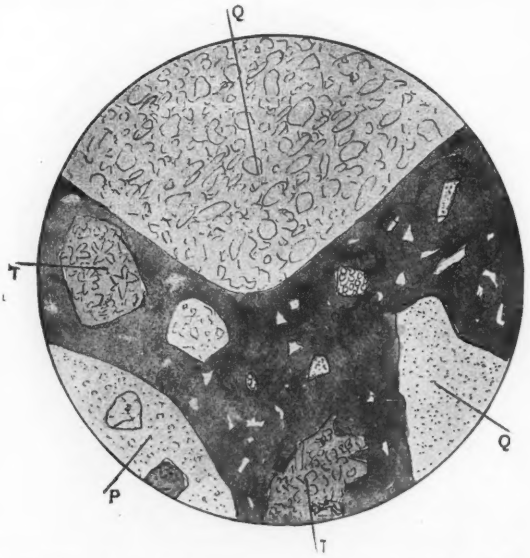


FIG. 63. Type *T*. × 28 Diameters. Analyser Removed. Breccia from Totoral. *Q* = Quartzite. *P* = Porphyry like Fig. 62, *S*. *T* = Radiating bunches of tourmaline replacing some fragment. Cementing material under high power seen to be tourmaline and cassiterite.

construction by an American company will cheapen the cost of production, that the present mine owners will reduce their prices and that foreign capital, modern machinery and up-to-date managers will make what the writer believes to be the richest mineral country in the world what it ought to be.

MICROSCOPIC NOTES ON THE ORURO TIN FIELD.

Fig. 56 (*M*). A quartz porphyry from Negro Pabellon, containing: (1) Large quartz phenocrysts with many inclusions, the phenocryst in the illustration contains a small crystal of tourmaline. (2) Phenocrysts of biotite now partially altered to tourmaline. Groundmass felsitic altering into mucovite.

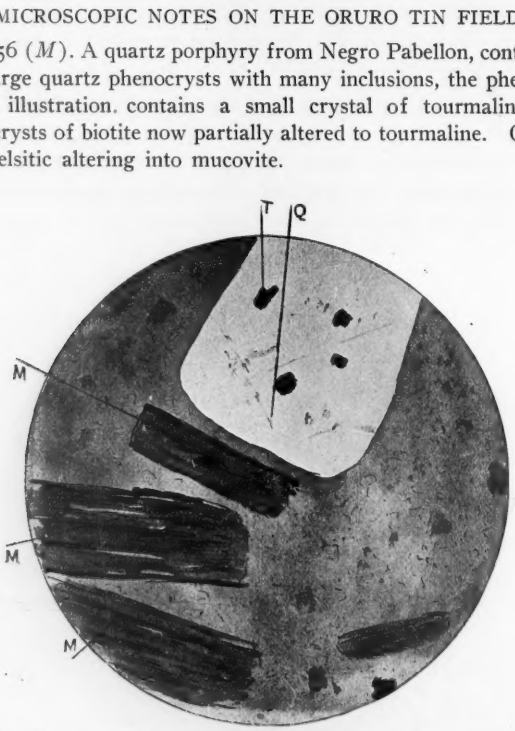


FIG. 64. Type *U*. × 28 Diameters. Crossed Nicols. Altered Quartz-porphyry from San José Lode, Uncia. Groundmass = Quartz and tourmaline. *T* = Pseudomorphs of tourmaline after Feldspar (?). *Q* = Quartz phenocrysts. *Q.Q* = Aggregates of secondary quartz.

Fig. 57 (*N*). Mica andesite from Negro Pabellon. Glassy groundmass with phenocrysts of plagioclase and biotite, also contains a considerable quantity of magnetite.

Fig. 58 (*O*). From the same quartz porphyry as (*N*), but from a locality where a number of dark brown phenocrysts apparently pseudomorphs were observed. In thin section these proved to be pseudomorphs of tourmaline, probably after felspar. There is also some secondary quartz.

Fig. 59 (*P*). A quartz tourmaline rock from Chualla (see Pazña district). Groundmass an intimate mixture of quartz and tourmaline with larger quartz crystals scattered through it. I am not prepared to say whether this rock was originally a quartz porphyry or quartzite.

Fig. 60 (*Q*). From the Cataricagua lode, Huanuni. A breccia cemented by oxide of iron, with cassiterite crystals scattered through the cementing material. The fragments of the breccia are chiefly quartzite and quartzite schist often very much decomposed.

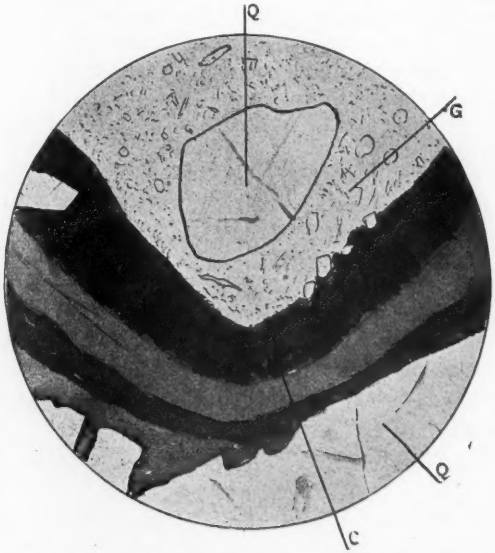


FIG. 65. Type *V*. ×28 Diameters. Crossed Nicols. Impregnated wall rock (porphyry) from Bismark lode. *Q* = Quartz phenocrysts. *G* = Groundmass of original porphyry altered to muscovite. *C* = Cassiterite showing crustification.

Fig. 61 (*R*). A biotite dacite from Huanuni. Glassy groundmass with phenocrysts of quartz, plagioclase and biotite.

Fig. 62 (*S*). Mr. Berkey writes: "Porphyritic rock from Totoral. Large quartz phenocrysts are prominent. Abundant phenocrysts of some dark mineral, presumably biotite, are now altered to an

aggregate of radiating tourmaline needles, forming a most remarkable set of pseudomorphous areas. Some secondary quartz is penetrated by these needles. The groundmass is holocrystalline, but exceedingly fine and even grained. No cassiterite is observed, although a few yellowish secondary grains resemble this mineral."

Fig. 63 (*T*). Mr. Berkey writes: "Totoral breccia. A breccia some of whose fragments are quartzite schist and some are quartz porphyry of type Fig. 62 (*S*). The cement is very dark and close-grained and much filled with fragments of various kinds of rock, especially quartzites of different grades of texture. In the cement also the tourmaline has prevailingly the same distribution as seen in Fig. 62 (*S*), *i. e.*, radiating bunches replacing some other grain or fragment. With high magnification it is apparent that tourmaline is the most abundant constituent of the cement and this together with very minute grains of cassiterite gives the chief color to the dark colored matrix.

Fig. 64 (*U*). From San José lode Uncia. The groundmass of the original quartz porphyry is now completely altered to a mixture of quartz and tourmaline. Phenocrysts of quartz are abundant and also phenocrysts of tourmaline replacing some other mineral, probably felspar. There is also secondary quartz penetrated by tuormaline needles.

Fig. 65 (*V*). From the impregnation of the walls of Bismarck lode, Uncia. Groundmass of the original porphyry now altered chiefly to muscovite. Quartz phenocrysts still intact. Cassiterite deposited in distinct layers round some fragment of quartz porphyry or quartz phenocryst. No tourmaline was observed in this slide.

GARNET CONTACT DEPOSITS OF COPPER AND THE DEPTHS AT WHICH THEY ARE FORMED.

CHARLES R. KEYES.

Heavy anhydrous minerals are well known to be frequent accompaniments of certain kinds of ore-deposits. The copious development of such minerals as garnet, topaz, tourmaline, biotite, amphibole and the like, in gangues is usually considered as taking place during the progress of intense local metamorphism of rock-masses under conditions of high temperatures and great pressure. With them metalliferous minerals also frequently develop and the ore-bodies thus formed constitute the type of true contact-deposits.

The conditions under which garnet-rock forms have received mainly only theoretical consideration. Definite data evaluating the various factors involved appear to have received little attention. Experiments by Chrustschoff[1] indicate temperatures reaching 550° C. It is generally admitted that high pressures are essential but the amount necessary is not so easily estimated. So far as is known to the writer no exact figures regarding the thickness of superincumbent rock have yet been made available. Their main significance is that they appear to reverse completely commonly accepted theoretical conclusions.

Contact-veins, as a title in the sense that was so long loosely used, is now practically abandoned. Authorities on ore-deposits have found it necessary to restrict the term so as to apply to those peculiar alterative effects which the exposed parts of rock-masses undergo when brought into close association with igneous intrusions. The process of the mineralization is usually regarded as taking place at a temperature somewhat above the critical point of water (365° C.), under great pressure as already stated, but without the intervention of fissures or cavities of any kind other

[1] "Neues Jahrbuch f. Geol., Pal. u. Hyd. f. 1891," Bd. II., pp. 86–90.

than the interstitial pores of the rocks. This conception has given rise to the deduction that true contact deposits are only deep-seated phenomena. Some writers even go so far as to assert that this class of ore-deposits is in reality formed only below the limits of the zone of rock-fracture, in the zone of true rock-flowage, or at depths of 25,000 to 30,000 feet, and that the examples open to observation have been brought to the surface mainly through the effects of enormous denudation which has produced the geography.

Most of the discussions on the subject are, as already intimated, purely theoretical in character. Little attempt is shown to secure actual facts bearing upon the critical points. No doubt concrete examples with measurable factors are exceedingly hard to find, and owing to the uncertain rate at which general erosion goes on the volume of overlying rock removed since the time when the metamorphism took place is difficult to estimate even approximately. The exact geologic period of the intrusion is usually hard to determine within reasonable limits. Most contact deposits of the limited class mentioned occur in the more ancient rock-masses and hence all of the critical factors are now wanting.

The San Pedro copper deposits of the Tuertos Mountains, and the Lucas copper deposits of the Ortiz Mountains, in New Mexico, have recently furnished both critical evidence and measurable factors. The first mentioned of these localities has been frequently cited as a type-example of true contact ore-bodies, formed under conditions of the zone of rock-flowage. The second is only a short distance away and furnishes additional desired data of exact values. The Jimenez copper deposits, in the state of Chihuahua, Mexico, supply other needed facts. The Mexico deposits are also cited as specific occurrences of contact deposits formed within the deep rock-flowage zone of the earth.

Since De Launay[1] first called special attention to the variations of metalliferous veins with depth, the theme has attracted wide notice. This author's main thought and the one which is so suggestive, is that owing to enormous erosion which many parts of the earth's crust have undergone we are able to observe in many

[1] *Rev. gen. des Sci. purée et appliqués*, t. XI., 1900.

instances portions of veins which were actually formed at great depths. Krusch,[1] in discussing the French author's work, cites a number of localities in which great denudation has taken place in comparatively late geologic times, the inference being that three to four miles, or more, of rock have been removed. Vogt[2] also supports the opinions of the writers mentioned, but is inclined to go farther and to greatly increase the denudation-units, multiplying the ordinary figures by ten.

Considering the zone of rock-flowage, or zone of anamorphism, as beginning at depths of from four to eight miles (8 to 12 kilometers), according as the rocks are weak or strong, Van Hise[3] regards true contact-deposits as developing only in this zone of anamorphism, where the temperature is above the critical temperature of water and the pressure above 200 atmospheres. "In those instances in which it is clearly shown that heavy anhydrous minerals, such as topaz, tourmaline, garnet and biotite, develop simultaneously with the depositions of ores by metamorphic processes, it seems highly probable that they formed under the conditions of the zone of anamorphism."

Among the typical examples which Van Hise especially notes are the Jimenez deposits of Old Mexico and the San Pedro copper deposits of northern New Mexico. Now it so happens that there actually exist for both of these localities definite data regarding the depth at which the present ore-bodies were below the surface of the ground at the time of their formation. It appears that the depths were very far short of the zone of rock-flowage.

The mining details of the San Pedro locality have been described sufficiently for present purposes by Yung and McCaffery[4]; but some of the geologic features of the region are not only instructive in the present connection but they furnish critical evidence upon moot points concerning the depths at which the ore deposits were originally formed.

The famous San Pedro copper mines are located on the western

[1] *Zeitsch. f. prakt. Geologie*, 1900, p. 317.
[2] *Trans. American Inst. Min. Eng.*, Vol. XXXI., p. 158, 1901.
[3] "Treatise on Metamorphism," p. 1056, 1904.
[4] *Trans. American Inst. Min. Eng.*, Vol. XXXIII., p. 355, 1903.

flank of the Tuertos Mountains, in the southern part of Santa Fe county, New Mexico. These mountains form a conspicuous cluster of sharp peaks of which there are three other similar groups in the neighborhood. These four lofty piles are arranged on a north and south line and are separated from one another by smooth plains six to ten miles wide. The most southerly of the four is the San Ysidro group; next are the Tuertos Mountains; then the Ortiz group; and finally the Los Cerrillos hills. These four isolated groups of mountains rise out of the surrounding plains as do volcanic isles out of the sea. They are all laccolithic in origin; and present marked structural contrasts to the other mountains of the region.

The Tuertos group consists of a number of sharp peaks rising nearly 10,000 feet above tide-level and 4,500 feet above the plains. The highest point is Oroche peak (Spanish for gold and silver mixture; a name locally corrupted to Oro Quay). The central mass is a gray mica-andesite. Only around the margins of the igneous body do the stratified beds appear, rising but slightly above the general level of the plains. On all sides except the west the rocks resting upon the laccolithic mass are yellow Cretaceous sandstones with some shale beds. On the west side a north and south fault brings the Carboniferous limestones to the surface. Huge plates of limestone are also included in the igneous mass. The San Pedro and neighboring mines appear to be opened upon the edges of such plates.

The laccolithic intrusions have entered at stratigraphic horizons that are definitely located in the geologic column of the region. The local rock-succession is that of the west side of the Rocky mountains rather than that of the better known east-side section. The general sequence of the rock formations and the maximum thicknesses represented in this area are as follows:

	Feet.
8. Quaternary loams and gravels	200
7. Tertiary marls and sands	1,500
6. Laramie (coal) shales and sandstones	800
5. Montana (coal) shales	500
4. Colorado shales	1,200

3. Mora[1] sandstones	500
2. Carboniferous shales and limestones	2,500
1. Azoic schists (exposed)	4,000

The close association of the Carboniferous limestones and the Cretaceous formations in the region is due largely to the fact that a great unconformity exists, permitting the latter often to repose directly upon the former.

In the Ortiz laccolith the main spreading apart of the strata is in the coal shales. These beds have always been considered as Laramie in age; but fossils recently obtained from the associated strata indicate that they more likely belong to the Montana division. The general geologic structure of the Ortiz mountains is represented below (Fig. 66). At the main coal camp of

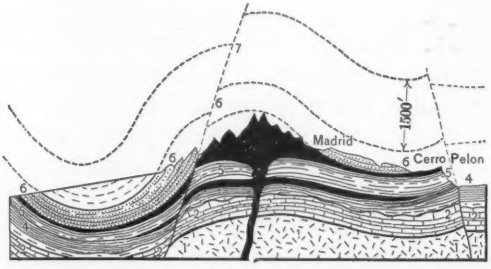


FIG. 66. Ortiz Laccolith, New Mexico.

Madrid, which is on the northeast flank of the mountains, there are four workable coal seams, together with about 350 feet of shales and sandstones, lying between two great andesitic sills. Each of the latter are from 200 to 300 feet in thickness; and extend several miles out from the main igneous body. The relationship of the sills to the coal seams suggest that the intrusive sheets themselves have probably followed coal-seams, perhaps the most extensive of all, as horizons along which they

[1] Named from the Rio Mora and refers to the so-called Dakota sandstone of the region as described by Hayden, Newberry and others; but does not include the Lower Dakota sandstone of Stevenson (*Journal of Geology*, Vol. XVI., p. 446, 1908).

were able to move most easily. Similar phenomena are not unknown in the Scottish coal-fields,[1] and in the coal-fields of Germany and Hungary, as noted by Moesta[2] and Von Rath.[3]

The thickness of the strata overlying the uppermost of the Ortiz sills could not in any case have been, when the laccolithic mass was formed, over 2,500 feet; or 3,000 feet even if the intrusion is considered as having taken place in the lower coal (Montana) section. As the intrusives doubtless occurred in early Tertiary time probably not one-half of the known Tertiary deposits of the region were yet laid down. A thickness of 2,000 feet of strata would in all likelihood be nearer truth for the actual volume of sediments floated upward in the formation of the Ortiz laccolith. In the main mass of the laccolith huge plates of Cretaceous strata have been involved. One of these plates, which is exposed near Dolores, is composed of sandstone, is 600 feet in thickness, and is highly metamorphosed. It is now standing on edge and is generally mistaken by miners for a quartz-reef. Another large plate is from the limestone. This crops out at the Lucas mine on the south side of the mountain. An auriferous pyrite zone six feet in thickness has for its hanging wall the altered limestone. The latter now resembles pisolite in which the grains are composed of garnets.

The Tuertos laccolith, on which the San Pedro copper deposits are situated, is similar in all respects to the Ortiz Mountains. The geologic horizon of the intrusion appears to be the same and the Montana sandstones and shales are upturned on the eastern flank of the mountains. The Carboniferous limestones on the west side, in the vicinity of San Pedro, appear to be elevated and tilted chiefly on account of faulting. The San Pedro mines are situated on a large slightly inclined plate of limestone and shale. This feature is also well brought out by Yung and McCaffery.[4] The limestone is altered to garnet-rock and the shales to black hornstone. The garnet-rock does not

[1] *Mem. Geol. Sur. South Staffordshire*, p. 118.
[2] "Geologische Schilderung Meissner u. Hirschberge," 1867.
[3] "Neues Jahrbuch f. 1880," p. 276.
[4] *Trans. American Inst. Min. Eng.*, Vol. XXXIII., p. 350, 1903.

always carry ore, but the copper ores are always found in the garnet-rock. This is also true in the center of the mountain group around Oroche peak (Fig. 67). In any case 3,000 feet of covering when the contact deposits were formed would be,

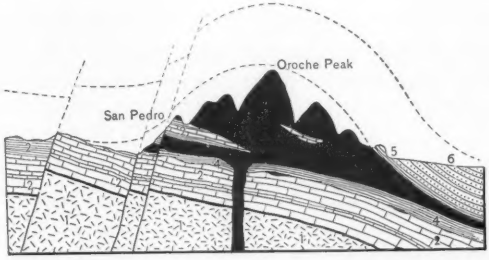


FIG. 67. Tuertos Laccolith, New Mexico. Garnetized Zone at San Pedro.

so far as present evidence goes, a maximum. Taking into consideration the character of the rocks this figure is barely one tenth of the covering required to bring the horizon within the zone of rock-flowage.

In the case of the contact-deposits of copper of Jimenez, in the southern part of the state of Chihuahua, Mexico, the data

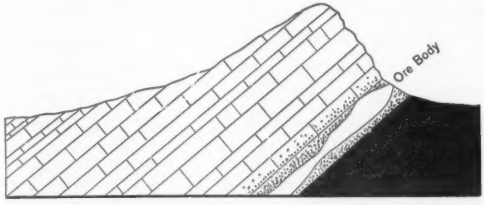


FIG. 68. Garnetized Contact Zone at Jimenez, Mexico.

relating to the maximum amount of overlying rock at the time of ore formation are not so precise as in the case of the New Mexican localities. A large granite mass creates a dome of the overlying Cretaceous limestones, the center being now removed through erosion. The relationships of these contact-deposits

are represented in the subjoined cut (Fig. 68) which corresponds in all its esential features to the briefly recorded observations of Weed.[1] There are no grounds for believing that there was ever a greater thickness of the strata above the present ore-bodies than about 2,000 feet.

As to the other American localities that have been especially cited as illustrations of true contact-deposits with which the heavy anhydrous minerals are prominently associated and which are regarded as formed under conditions of the zone of rock-flowage, no exact data are yet available concerning the thickness of the superjacent rock-masses. The Oregon localities[2] and the Idaho camps[3] are so situated that definite figures can be readily obtained. From what is already known of these places it is not at all probable that the depths at which the ore-bodies were formed are any greater than in the instances of the Ortiz and Tuertos deposits.

It would seem therefore that garnetization is a phase of contact metamorphism that is not necessarily associated with the zone of rock-flowage, but that it takes place at very moderate depths, under pressures that are less than one-tenth of the crushing strength of rocks.

[1] *Trans. American Inst. Min. Eng.*, Vol. XXXII., p. 404, 1902.
[2] U. S. Geol. Sur., 22d Ann. Rept., pt. ii., p. 629, 1901.
[3] *Ibid., 20th Ann. Rept.*, pt. iii., p. 189, 1900.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

ORIGIN OF THE GOLD OF THE RAND GOLD FIELD.

SOME FEATURES OF THE RAND BANKET.

Sir: In 1897 I did my best to assist in explaining the banket of Johannesburg.[1] I have not since visited South Africa and feel somewhat reluctant to return to the subject, even at the invitation of the editor, yet a few comments on Mr. Gregory's papers[2] and the discussion to which his views have given rise occur to me and may possibly tend to clarify the situation.

Those who adhere to the hypothesis of infiltration of the Rand banket assume that the matrix of the pebbles is less compact than the quartzitic sandstone which forms the walls of the deposit. I paid especial attention to this feature during my visit to the mines and made many comparisons both megascopic and microscopic without being able to detect any difference between the two in the size of the grains, their mineralogical character or the degree of silification attending metamorphism. In this respect I am borne out by the observations of Mr. Ross Browne, who contributed to the discussion of Mr. Gregory's paper in the *Transactions of the*

[1] "The Witwatersrand Banket, with Notes on Other Gold-bearing Pudding Stones," U. S. Geol. Surv. 18th Ann. Rep., Part V. Also Amer. Jour. Sci., Vol. 155, 1898, p. 193.

[2] *Trans. Inst. Min. and Met.*, Vol. 17, 1908, p. 1, which is followed by a discussion by various geologists and engineers. Also a paper which is essentially an abstract of the above, this JOURNAL, March, 1909.

Institute of Mining and Metallurgy. Mr. Browne's statements may perhaps serve as an answer to the doubts of Mr. J. Malcolm Maclaren, who says that I assume this point. Doubtless I should have been more explicit. Had there been any such difference as Mr. Maclaren suspects it would almost surely have shown itself in the degree of silification which attended metamorphism, and secondary quartz would have been more abundant in the banket than in the walls. It seems to me that the deposition of the sand and pebbles on the ancient beaches of the Rand must have been extremely similar to that which can be observed to-day on sand beaches along fairly rocky coasts, such for example as those of Massachusetts Bay. In such localities very violent storms throw up banks of cobbles far beyond the line of mean high water and these storm beaches contain extremely little sand. On the other hand a surf somewhat heavier than the average will deposit below high water mark layers of pebbles of an inch in diameter, more or less. These pebbles are of course moved by waves with considerably more difficulty than the fine sand of the beach because the grains of sand present a greater surface per unit of mass, and in the quieter water of subsequent tides such a layer of pebble is evenly filled in and covered over with ordinary sand. When by artificial excavation or otherwise a cross section of the beach is exposed, these layers of pebbles may be seen in place and the toute ensemble corresponds in most respects to that of a cross section of the banket with its quartzite walls.

Mr. Maclaren appreciates the force of my arguments as to the effect of pebbles in the sand on the permeability of the mass, but possibly it is worth while to state the matter in a slightly different form. Suppose a uniform Tertiary sandstone with any representative interstitial space, say 20 per cent., and imagine that in this sandstone spherical nodules develop, as they so frequently do in sandstones. Such nodules are very firmly cemented and are substantially impermeable to liquids. It is evident that each nodule reduces the amount of interstitial space and will impede the passage of any solution which may tend to percolate through the mass. If the nodules were to develop at appropriate uniform distances and to such a size as just to touch one another, they

would reduce the interstitial space of the sandstone to 25.95 per cent. of its original amount;[1] so that if this latter were 20 per cent., the residual interstitial space would be only a little more than 5 per cent. Under such conditions a permeating solution would evidently impregnate the layer or space occupied by the nodules to a very much smaller extent than the surrounding sandstone supposed free from nodules; for the sandstone would have nearly four times as much space available for ore deposition as the nodular layer. Precisely in the same way, as it seems to me, if impregnation had occurred on the Rand the gold values would be found smaller in banket layers than in the adjoining quartzitic sandstone, for each pebble would act like one of the hypothetical nodules. The only way of refuting this reasoning would be by a demonstration that the matrix of the pebbles is in fact now, or was before metamorphism, of a totally different character from the adjoining rock. I know of no observations which bear out this thesis; on the contrary, Mr. Browne and I, who have each paid attention to the subject, find it impossible to draw a distinction.

It is difficult for me to imagine how a substantial difference between the matrix of the banket and at least one wall could have been brought about. Suppose the sand underlying the pebbly layer had been silted up with clay just before the pebbles were spread over it; the pebbles would none the less be covered in with the same sand which forms the hanging, and if this too were to be silted up so also would be the interstitial sand of the pebble layer. In either case the hanging would be more permeable than the banket because free from pebble, and after impregnation would carry greater value.

Mr. Gregory is very emphatic in the expression of his belief that pebbles of pyrite do not and cannot exist in the banket and he ascribes the pebble-like masses of pyrite to pseudomorphosis after pebbles of iron oxide, or in other words, the conversion of hematite pebbles into pyrite by the action of soluble sulphides. In his original paper he says, "pyrite is so easily oxidized and

[1] "Quicksilver Deposits of the Pacific Slope," U. S. Geol. Surv. Mon. XIII, 1888, p. 399.

so brittle that its occurrence in a placer deposit seems highly improbable." In New Zealand he met with no such occurrence. In his paper in ECONOMIC GEOLOGY he states that the occurrence of rounded pebbles of pyrite in an ocean is most improbable from chemical considerations.

I have never been in New Zealand and know substantially nothing about the placer deposits there, but on the Pacific Slope of North America and in the Ural Mountains it is certain that pyrite pebbles in placer deposits are no rarity. Some pyrite, to be sure, is easily decomposed, but it has long been known that pyrite uncontaminated with marcasite or pyrrhotite offers great resistance to oxidation. Sir Archibald Geikie says, "pyrite when free from marcasite yields but slightly to weathering, hence its cubical crystals may be seen projecting still fresh from slates which have been exposed to the atmosphere for several generations."[1] This is well recognized; for example Mr. Donald Campbell in his article on slate in the Encyclopedia Britannica states that "some of the most durable slates are sprinkled with pyrites without detriment." Mr. A. A. Julien has also made an elaborate investigation of the decomposition of pyrite, and he came to the same conclusion as Sir Archibald. Normal pyrite, he says, resists oxidation so well that mere surface alteration is often the final condition.[2] On the Pacific Slope of the United States much of the pyrite exhibits great resistance to weathering. On the dumps of the Comstock Lode and of mines along the Gold Belt large quantities of pyrite have been exposed to the action of the atmosphere for years and yet this sulphuret remains almost untarnished. In this connection a score or two of years is not an insignificant period; for during each year winter frosts and spring rains must furnish to the river placers contributions of material from the gold-veins. As for the brittleness of pyrite, this is of course a relative term, but it is easy for anyone to convince himself that pyrite is vastly less brittle than quartz. This must be familiar to every chemist or assayer who has attempted to bray

[1] Text-book, 4th edition, 1903, 108. The same passage also occurs in the edition of 1882.

[2] *Annals New York Academy of Science*, Vol. 4, 1887, p. 213.

these minerals in a mortar. Grinding pyrite is indeed a matter of much labor and the behavior of this mineral in a mortar is very indicative of the degree of resistance which it would offer to the abrasive action of pebbles in a stream or on a beach. To what chemical considerations Mr. Gregory refers I do not know. The weathering of pyrite offers a very difficult and complex problem, but why sodium chloride should have any effect in accelerating the decomposition of this sulphuret I cannot guess. Certainly the monosulphide of iron is commonly precipitated during analyses in the presence of sodium chloride and is therefore stable under these conditions. Among the mines in semi-arid regions pyrite has been exposed for ages to the action of percolating waters very considerably charged with sodium chloride and yet remains quite fresh. The only direct observation as to the effect of sea water on pyrite known to me, was made by Mr. D. S. Martin,[1] who found at a bluff at Cliffwood, New Jersey, nodules of marcasitic pyrite which in the air decomposed with great rapidity, generating free acid and disintegrating, while those which fell into the sea water merely became superficially brown or hepatic, and subsequently underwent no sensible change. So much for inferences. It is more instructive to turn to direct observation.

So far as fresh water placers in America are concerned, there is no room to doubt the frequency of the occurrence of pyrite pebbles. For generations prospectors on the Pacific Slope have recognized that rounded pebbles of pyrite afford an excellent indication of the presence of placer gold and very important discoveries have been made by this means. In river placers such pebbles are sometimes found which weigh several ounces, and from these to mere sand grains measuring a fraction of a millimeter in diameter they are common. Mr. David T. Day[2] has examined the approximate mineral composition of nearly 700 sands and tailings of placer deposits of the western United States, communicating the results for pyrite specifically, indeed, only in cases in

[1] *Annals New York Academy of Science*, Vol. 4, 1887, p. 125.

[2] "Black Sands of the Pacific Slope in 1905," Bulletin U. S. Geol. Survey, 1907.

which it was strikingly abundant. Thus the hydraulic tailings from Junction City contain 304 pounds of pyrite per ton and concentrated sand from the Orleans mine 122 pounds of pyrite per ton; the concentrate from ground sluicing at Beaver Creek 536 pounds of unclassified material per ton, mostly pyrite. Mr. Day, however, has also given a table of frequency of occurrence deduced quantitatively from all his experiments. From this it appears that the frequency of the following minerals is in the order in which they are set down: feldspar, epidote, olivine, pyrite (including chalcopyrite, arsenopyrite and pyrrhotite), monazite, limonite, rutile, pyroxene, apatite, titanite.

Mr. Day examined the auriferous sands from the coast of California and Oregon as well as fresh water placers. He informs me that pyrite pebbles are common in the sands of Crescent City, California, and elsewhere along the coast. These pebbles are not considerably oxidized, that is, not enough to interfere with their instant identification as sulphurets. The gold-bearing beaches of Alaska have also been examined to some extent by members of the Geological Survey, especially under Mr. Alfred H. Brooks.[1] The beach sands of Nome are described as carrying pyrite, without any comment or evidence of surprise; indeed, I am told that its occurrence there is frequent. I have before me a sample belonging to Mr. Brooks of concentrates from the Gibson claim on the "sub-marine" beach at Nome, Alaska. The sub-marine beach represents a beach now submerged 34 feet below the sea level and as the coast seems at present to be rising it is undoubtedly a great many years since the sands which it contains were accumulated; in fact, there is some paleontological evidence that it is of Tertiary age. The concentrates consist mainly of pyrite; the black sand and quartz grains not composing more than possibly 10 per cent. of the mass. The specimen is perhaps overconcentrated, but Mr. Philip S. Smith, who collected it, informs me that the original sand contained considerably more pyrite than black sand. The pyrite all shows evidences of abrasion and the grains vary from sub-angular to sub-ovoid. The larger, roundish

[1] "Reconnoissance in the Cape Nome and Norton Bay Region." Special Publication U. S. Geol. Survey, 1901.

pebbles are about a quarter of an inch in diameter and the grains range from this size downwards to particles of not more than one hundredth of an inch in diameter. In many cases crystal faces are still recognizable, although the edges of the crystals are abraded. There are also cleavage fragments presenting the usual characteristic surfaces. This pyrite is not badly tarnished and has not suffered decomposition to any important extent.[1] I have never visited the placers of the Ural Mountains, but the descriptions leave no question whatever as to the frequency of pyrite pebbles in that region. As long ago as 1842 Gustav Rose stated that pyrite in small, loose grains was more or less abundant in all the placers of this region, but always converted into limonite. In speaking of the Adolphskoi deposit, however, Rose remarked in 1837 that pyrite is more abundant in this gold sand than in any other among the Ural Mountains, magnetic iron sand being present in relatively very small quantities. He described the pyrite as very well preserved, although it has grown brown. Whether he meant that the color is changed through and through or only externally he did not say.[2] N. von Kokscharow also states that pyrite occurs in the placer deposits of every district. In the placers of Nischne-Tagilsk the same authority remarks that the pyrite is superficially oxidized while the kernels of the grains are fresh.[3] Again R. W. Jeremejew[4] states that in the Orenburg district fresh pyrite occurs in the placers as well as the same mineral in an altered condition. The pyrite changes first to limonite and this passes over to hematite.[5] I may observe

[1] A few more references to the occurrence of pyrite in American placers may be welcome. The list could be extended. B. Silliman observed pyrite in the Cherokee washings, *Amer. Jour. Sci.*, Vol. 6, 1873, p. 133. J. D. Whitney commented on the auriferous sulphurets of the deep leads at Manzanita Hill and French Corral, Auriferous Gravels of the Sierra Nevada, 1880, p. 390. Mr. John Hays Hammond in his paper on the auriferous gravels of California states that "zircon, magnetic [?] pyrites and garnets are the most abundant minerals accompanying the gold," Ninth Ann. Rep., State Mineralogist of Cal., 1890, p. 119.

[2] Reise nach dem Ural, Vol. I., 1837, p. 367, and Vol. II., 1842, p. 462.

[3] *Materialen zur Mineralogie Russlands*, Vol. 6, 1866, p. 342.

[4] *Groth's Zeitschrift*, Volume 15, 1889, p. 531.

[5] In describing the auriferous gravels of the Lena basin Mr. A. Bordeau states that the gray concentrates of the gravel washings are derived from the

that it is a matter of local detail whether the pyrite in the placer deposit is or is not converted into limonite. Where the gold-bearing sands are constantly exposed to the action of the atmosphere, as those near the surface often are, pyrite will of course eventually become oxidized. On the other hand below permanent water level or, as California miners would express it, in the *blue leads* such oxidation does not take place and reduction is more likely to occur. Even where vegetation such as grass covers gold-bearing sands, pyrite does not appear to change to limonite. Thus if in the Ural Mountains there are any fairly deep placers no doubt an abundance of fresh pyrite would be found.

On the Rand Mr. Gregory interprets as pseudomorphs both the occasional smooth, fairly large pebbles of pyrite and also the very numerous pyrite grains which can be studied only under the microscope. Now Mr. Koch pointed out long since that the grains of pyrite visible in the slides are generally shaped by attrition or at least display rounding of the edges and corners. This was confirmed by Mr. Pelikan. Mr. DeLaunay called especial attention to the fact that the pyrite often occurs in grains which are rolled or at least broken, blunted or rounded. He regards these pyrite pebbles as auriferous and mentions having observed under the microscope gold imbedded in the pyrite.[1] My own observations entirely confirm those just mentioned. In my slides there occur pyrite crystals in every condition of attrition from slight blunting to almost perfect reduction to a spherical form. Where no crystal faces are observed it may be impossible to decide whether the pyrite is an original mineral or pseudomorphic, but where the original faces are still recognizable it is clearly impossible to doubt whether one has to do with pseudomorphs of pyrite after hematite and magnetite or with pyrite which crystallized in

gray auriferous pyrite crystals of the bed rock schists. *Revue Universelle des Mines.* Vol. 1, 1903, pp. 151 to 153. Mr. Ernst Maier has given an account of the gold placers of the Amgun region on the eastern coast of Siberia in which he mentions that "associated with the placer gold are pyrite, magnetite, stibnite and rarely garnet." *Zeitsch. für Prak. Geol.,* Vol. 14, 1906, p. 120.

[1] My own paper, p. 18.

its own proper form before the blunting and rounding took place. Since in hundreds of cases this original form is traceable, I cannot agree to Mr. Gregory's conclusion that the pseudomorphism is universal or even general. Indeed, I question very much whether hematite can be converted into pyrite without showing distinct evidence of the process. I have had some occasion to study the substitution of pyrite especially for hornblende in the wall rocks of the Comstock Lode. In such cases the original mineral is replaced by a group of crystals of pyrite of which the individuals are distinct, and only the general outlines of the host are preserved as an indication of the process. That a smooth pebble of hematite or magnetite should by pseudomorphosis be converted into a smooth pebble of pyrite appears to me extremely improbable.[1] Unfortunately I have no specimens of this kind at my command, but I suggest that if such pebbles were to be sliced and etched it might be apparent whether the mass was really a congerie of minute pyrite crystals or an homogeneous individual.

Comparing the pyrite from the concentrates of the sub-marine beach at Nome with that of my slides of the banket, I find that every type of the Alaskan pyrite is represented in the banket. On the other hand in the banket there are pyrite masses more completely and perfectly rounded than any in the specimen from Nome.

On the whole, then, I feel obliged to conclude that the rounded pyrite of the banket is at least in part a real and original pyritic sand. I have adduced ample evidence to show that such occurrences of pyrite are far from unusual. The evidence of the slides is that the pyrite particles in the banket are in large part original sulphurets, not pseudomorphs after any other mineral.

That a portion of the pyrite in the banket may be and probably

[1] According to Hintze's great handbook of mineralogy, pseudomorphs of pyrite after hematite have been observed. I find no record of the replacement of magnetite by pyrite, but magnetite is sometimes converted to hematite. When pseudomorphs of pyrite form after hematite, the volume increases in the ratio $48/31 = 1.55$ this being twice the ratio of the molecular volumes of pyrite and hematite. If a pebble or crystal of hematite were firmly imbedded in quartzite and then converted into pyrite, something would have to give way. If magnetite were to be directly converted to pyrite the increase of volume would be in the ratio 1.60 to 1.

is secondary I maintained in my former discussion of the subject. It is hardly conceivable that secondary pyrite should not have formed in these ancient rocks. At the croppings the sulphurets have weathered and were partially converted into iron sulphate which has percolated downwards along the beds. The reefs, being beach deposits, of course contained more or less organic matter, more in some spots than in others and, as is well known, remnants of carbonized organic matter are still to be found here and there in the banket. This organic matter would reduce iron sulphate and unquestionably has done so. This process is notoriously very common everywhere and it would be rather surprising to find strata at least as old as the Paleozoic in any part of the world in which no pyrite could be detected as a result of reduction; but at the upheaval of the Rand strata the injection of norites was probably accompanied by sulphurous emanations and gave rise to some development of pyrite among the beds without, however, affecting the question of the origin of that portion of the pyrite which is most intimately associated with the gold.

A great deal has been made of the occurrence of crystallized gold at some points on the Rand. Equal attention has not been paid to the fact that its most common occurrence is not crystalline in the ordinary sense of that term, that is to say, the scales usually show no crystal faces. Most of the gold is in excessively fine, thin flakes, entirely comparable with those to be found on modern beaches and, as has been pointed out by Mr. DeLaunay, many of them are so thin as to be translucent. I found it almost essential to examine my slides in full incident sunlight in order to detect such particles. Under these conditions the microscope reveals great numbers of them. Some of them are crinkled by the pressure of sand grains, but that fact does not obscure their history. They do not resemble grains of gold in vein quartz.

Mr. R. Beck considers that the existence of copper pyrite and galena in very small quantities on the Rand indicates infiltration, but here again experience points to a different explanation. Mr. D. T. Day informs me that at the Kerby district in southeastern Oregon galena is abundant in some of the placers and chalcopyrite is also certainly present in some of the California gravels.

How can it be otherwise? A placer mine consists of the materials found in gold quartz veins, ground up and mixed with country rock and partially concentrated. It therefore seems inevitable to suppose that all the minerals to be met with in the quartz veins will also be met with in the placers. If they are not there detected it must be from lack of careful search or because the particular placer investigated has been so long exposed to the weather as to bring about complete decomposition. Most of the black sand of placers comes from the country rock and when it happens that this is relatively free from iron oxide so too will be the placer.

It should be needless to insist that the characteristics of modern placers must be taken into consideration in deciding whether or no the Rand deposits are ancient placers. In modern placers quartz pebbles carrying any considerable value are very rare; in modern beach placers the values are found at the under side of layers of what I may call heavy particles sometimes composed only of black sand, sometimes of pebble and black sand, sometimes nearly free from black sand. By heavy particles I mean those which have relatively large mass per unit of surface. Modern placers occasionally contain galena and chalcopyrite, while rolled fragments of pyrite (more or less marcasitic or pyrrhotitic) are common both in America and Russia and sometimes the pyrite is a predominating constituent. Beach placers are sometimes auriferous for long distances, many miles, and the gold in them is much more uniformly distributed than in any gold-bearing vein.

The Rand shares all these features of modern placers, each of which, however, has been adduced as evidence that the banket differs essentially from a placer deposit. When these characteristics are duly appreciated, when also the permeability of conglomerates is logically analyzed and allowance is made for the very moderate amount of metamorphosis or secondary action in this extremely ancient deposit the genesis of the Witwatersand banket seems to me sufficiently clear. To be sure the Rand is very remarkable for its high tenor and its total value is phenomenal, even portentous; but in such respects only exceptional

deposits become famous. It does not follow that because the value of the deposit is exceptional, the method of deposition should be mysterious.

In the foregoing pages I have enlarged upon only a few of the points dealt with in my earlier papers, the conclusions of which I see no reason to modify.

GEORGE F. BECKER.

REVIEWS

Magnetite Deposits of the Cornwall Type in Pennsylvania. By ARTHUR C. SPENCER. Bull. U. S. Geol. Survey No. 359, 1908.

The Cornwall mines of Pennsylvania have yielded more than twenty million tons of 45 per cent. ore high in sulphur and low in phosphorus. The open cut at the principal mine is of the same order of magnitude as some of the Mesabi open pit mines of Minnesota. Though mined since the early part of the nineteenth century and repeatedly studied by Pennsylvania and other geologists, an adequate account of these ores and their origin has not been available to the general reader until the appearance of A. C. Spencer's Bulletin on Magnetic Deposits of the Cornwall type. His conclusions briefly are these:

The ores are replacements of limestones, limy shales and limestone conglomerates, less commonly of clay shales or sandstone, of both Mesozoic and Paleozoic age. The gangue material is the unreplaced part of the sediments. They are usually associated with large masses of diabases, sometimes with smaller masses. The solutions which have deposited the ore are thought to be juvenile solutions, in the condition of vapor, expelled from the igneous rocks and carrying the iron directly from the magma. It is argued that meteoric solutions could not have done this work, even with the aid of heat from the igneous intrusions, for the reasons: (1) Meteoric solutions could never approach the heated bodies of rock and would be likely to segregate the ores at a little distance away from the igneous contacts rather than at them. (2) There is no evidence either for or against the leaching of iron from the adjacent sandstones and shales, which carry 5 per cent. to 8 per cent. of iron oxide, the generally bleached condition of these rocks near the ore being possibly due to the reduction of the iron. Moreover, bleached rocks are not always accompanied by ore deposits. (3) Finally, the deposits are neither as numerous nor as widely distributed as would be expected if the iron had been contributed by the invaded formations. The only evidence cited against the juvenile origin of the waters and ores is the fact that ores do not in all cases accompany the igneous rocks, but as opposed to this it is argued that it is by no means necessary to believe that identical materials must have been introduced everywhere in the vicinity of intrusive masses.

Widely varying metamorphism of the sedimentary rocks is largely

due to the variation in the direction of the paths by which the intrusions came to their present positions, because the deep reservoir is conceived to be the original source of all the energy involved in metamorphism. In general the amount of contact metamorphism in the sediments outside of the iron is remarkably little, the minerals characteristic of contact metamorphism being so uncommon as almost to escape observation.

The report is accompanied by satisfactory detailed maps and descriptions of the principal ore deposits, though additional quantitative data on the chemical, mineralogical and physical characteristics of the ore would be desirable.

Dr. Spencer's conclusion that the ores have been contributed hot from igneous sources is similar to the one he has recently reached for New Jersey magnetites.[1] The cited evidence for this conclusion is less positive for the Cornwall ores than for the New Jersey ores, and correspondingly more emphasis is placed on negative evidence that meteoric waters have not done the work.

C. K. LEITH.

Mineral Resources of Virginia. By THOMAS LEONARD WATSON, PH.D. The Virginia Jamestown Exposition Commission, 1907.

"The Mineral Resources of Virginia" is an excellent and exceptionally full summary of the economic and geologic relationships of the mineral wealth of the state. Part I. of the report deals with the general geology of the state. Part II. is a summary on the building and ornamental stones, cements and cement materials, and clays. The chapters on cements and clays are by R. S. Bassler and Heinrich Ries, respectively.

The value of the production of granite, slate, sandstone and limestone for building purposes in 1905 is estimated to be $800,000. Granites are quarried in the piedmont region, especially in the vicinity of Petersburg, Richmond and Fredericksburg. The valuable roofing slates are gotten principally from the Ordovician in Buckingham County, while workable sandstones occur in all the geologic horizons of the state. Those of the Newark are most in demand. All the physiographic provinces of the state have limestones, but those of the piedmont are the most important commercially. The Shenandoah, Chickamauga and Lewiston are all productive, particularly the latter is known for its marbles.

Western Virginia is the important cement area. In geologic order the cement producing horizons are:

4. Greenbrier (Mississippian) limestone.
3. Lewiston (Helderberg) limestone.

[1] Geol. Atlas U. S., Franklin Furnace Folio, No. 161, 1908.

2. Ordovician (Trenton) limestone and shale.
1. Cambrian impure limestone and shale.

Virginia has materials for Portland, natural and pozzuolana hydraulic cements. They are widely distributed as limestones and shales, especially in the Ordovician, whose materials are commonly favorable in composition. The report contains many analyses and other statistical material.

The clays of Virginia are classed as residual and sedimentary. In the crystalline schists of the piedmont there are feldspar pegmatite veins whose decomposition has given rise to clays of great purity which are used for pottery. The impure residual clays of the Cambro-Silurian of the Great Valley derived from the decomposition of limestone are used for brickmaking. The sedimentary clays are common on the coastal plain and in the region west of the Blue Ridge. They support an enormous brick industry. The report offers a large number of chemical and physical clay tests, and many details on distribution which have considerable economic and scientific interest.

Part III. deals with non-metallic minerals; namely, graphite, sulphides, halides, oxides, silicates, phosphates, sulphates, coal and miscellaneous products. The producing coal formations are the Newark, Mississippian and the Pennsylvanian. The bituminous coal seams of the Newark are interstratified with sandstones and shales. They are folded and faulted and cut by numerous dikes, which makes it difficult to estimate their value. The coal of the Mississippian has great areal distribution, but is not as important as that of the Pennsylvanian. It is the latter which places Virginia fifteenth among the coal producing states of the union. The two principal fields of the Pennsylvanian are the Pocahontas or Flat Top coal field and the Big Stone Gap coal field. A large number of analyses and other data indicate the excellent steam, coking and cokeless qualities of these coals.

Part IV. is concerned with the metallic minerals or ores. R. J. Holden introduces the chapter on iron with a brief historical sketch of the iron and smelter industry of the state. Throughout the early history of the iron industry in America, Virginia took a leading and aggressive part. The first iron ore mined in America was mined in 1609 by the Jamestown colonists. It was shipped to England and there reduced to metal. Following this venture the first iron works in America were erected about a mile south of the present site of Richmond, but they were destroyed before they were operated, during the Indian War of 1622. The early industry was restricted to the pyrite deposits because of the proximity of these to waterways. With improvements in transportation the industry gradually spread to the magnetite, brown ore and hematite fields. The advent of the railroad opened up new fields to shipment. It also

caused an expansion of the charcoal and smelter industry which culminated in the boom of the 80's of the last century, and ended with the panic of '93. Recent railway development, as well as the discovery of new fields are now presaging a healthy growth in the future. The total value of Virginia's production is estimated to be $36,000,000.

The ores of Virginia are limonite, hematite and magnetite. The limonite or brown ores occur as replacements of limestone by iron which was leached from adjacent formations; and as residual materials somewhat concentrated by mechanical and chemical agencies, which are derived from the decomposition of limestone, shale and iron sulphide formations. The hematites are bedded, sedimentary deposits, interstratified with limestone and shale. Magnetite occurs in sheet-like formations interleaved with crystalline schists, limestones and quartzites; as secondary deposits in association with the Shenandoah limestone; and as titaniferous magnetites in a variety of associations. The common impurities of the limonite ores are from 10 to 20 per cent. silica; 1 to 6 per cent. of alumina in washed ores, and from .1 to .4 per cent. phosphorus. The phosphorus content is higher in fault deposits. Manganese is variable. Gossan limonites commonly contain sulphur. More than .1 per cent. of sulphur usually makes an ore unmarketable. Lime occurs in objectionable quantities in some hematite ores. Magnetites commonly contain titanium, which is objectionable in amounts greater than 1 per cent. The iron content of the marketed materials varies from 38 to 45 per cent.

The principal iron-producing rocks are Silurian. The ores are hematites, limonites and magnetites. Limonites and hematites are also found in the middle Cambrian and at the base of the Devonian in juxtaposition with upper Silurian deposits. Magnetite is found in the Silurian and in the schists of the piedmont belt. The latter also contain the pyrite and pyrrhotite deposits. The so-called Oriskany limonite of the upper Silurian and lower Devonian is a clayey ore which occurs as replacements of the upper limestone beds of the Helderberg or of the lower Devonian shale beds. The iron was derived from the Devonian shales by leaching. It generally outcrops on the lower slopes of anticlinal mountains, whose exposed cores consist of Clinton and Medina sandstones. Along the strike continuous exposures of ore for a distance of half a mile are common. Its thickness is controlled by the thickness of the upper bed of the Helderberg, which may vary from 8 to 35 feet. Along the dip, the ore is known to have an extension of 700 feet. The ores are washed and yield from 50 to 80 per cent. of merchantable product. The Clinton formation of the Silurian bears fossil hematites at three horizons. They are bedded deposits interstratified with shale and limestone. Their outcrop is generally on the upper slopes of anti-

clinal mountains or in monoclinal succession in low lying areas, depending on the durability of the underlying formations. The maximum thickness of the beds is four feet, and the minimum workable thickness is 16 inches. The ore is either fossiliferous or oolitic. The lime in some is objectionably light but the phosphorus content is low. The Shenandoah limestone of the Silurian produces both limonite and magnetite. The limonite occurs in clay banks near the base of the formation, on the lower slopes of anticlinal hills of Cambrian sandstone and shale. From 3 to 30 per cent. of the clay bank is minable ore. This is in coarse nodules and in fine grains. The deposits are residual and have been derived from the decomposition and solution of the limestone, with some mechanical and chemical concentration. The Silurian magnetites occur as secondary deposits in the Shenandoah limestone of Giles and Washington counties. The ore bodies are derived from the leaching of the overlying stale. They are small and are only worked intermittently. The hematites of the Cambrian are chemical sediments which occur in the Blue Ridge as a bedded, fractured, massive deposit interstratified with a great shale formation. They outcrop from 500 to 1,000 feet above the valley. Their intense folding has caused flowage, resulting in a thickening on the crests of the anticlines and a thinning on the limbs. The ores are persistent for miles along the strike and have been followed several hundred feet down the dip. Their thickness varies from three to six feet.

The limonites of the Cambrian are found in irregular masses in steeply dipping sandstones and shales, and in fault zones in sandstone. The shale ores usually outcrop in benches on the lower slopes of anticlinal mountains. Their maximum extent along the strike is a quarter mile. They are up to 80 feet wide and have been followed to a depth of 200 feet. The fault deposits are free from clay but are unusually high in phosphorus. They have a known maximum width of 20 feet. The iron was derived from the leaching of the shale.

The pyrite gossan ores of the piedmont were the first ores mined in Virginia and were exploited for two centuries but are no longer exploited. They are widely distributed east of the Blue Ridge, and occur in veins interlayered with schists. The geological occurrence of the pyrrhotite gossan deposits is similar to that of the pyrite gossan. They are found in veins reaching a thickness of more than 100 feet, and persistent for miles along the strike. The latter conforms with the strike of the enclosing schists. Their principal occurrence is in the plateau region in Carrol County. They are not mined at the present time. The piedmont magnetites are in tabular vein-like masses which strike and dip with schistosity of the enclosing rocks. Their width is from 4 to 12 feet, and the explored depth is several hundred feet. The associated

rocks are hornblende, mica and talc schists, quartzites and trap dikes. The production has been small and the mines are abandoned. The ore minerals are magnetite, specular hematite and limonite.

The geographical distribution of the ores is determined by the structural and topographic characteristics of their associated formations. To the general reader their distribution can best be described in terms of the major physiographic units. The magnetites outcrop principally on the piedmont plateau and in the Blue Ridge. The Cambrian limonites and hematites are found in the Great Valley and on the Blue Ridge. The limonites, hematites and magnetites of the Silurian are found principally in the Alleghany mountain region. Holden describes the distribution of the ores in terms of local units and recognizes the following areas: the piedmont area, the pyrite area, the great gossan area, the Blue Ridge area, the fossil area, the New River-Cripple Creek area, the Great North Mountain area and the Oriskany area.

The author gives a large number of detailed descriptions of mines, which afford a fund of interesting data on the relation of the distribution and character of the ores to structural, topographic and other geologic features.

A considerable amount of the Virginia ore is mined by open cut steam shovel methods. Open cut mining is also done by sluicing, milling, hydraulicing and by pick and shovel. In underground mining shaft and tunnel and pillar and room methods are employed.

Nearly all the ores are washed and constitute from 3 to 25 per cent. of the material mined. The clay is taken out by log washers and the sand by revolving screens, which receive the material from the log washers. Jigging and hand sorting are rarely employed.

Holden's chapter is the best summary published on the geologic and economic aspects of the iron ores of Virginia. The report is readable and has all the interest that comes from thorough conversance with the facts.

With a single exception all the commercial deposits of *lead* and *zinc* are confined to the Shenandoah limestone of the Valley region. In the Valley this formation is thrown in a series of N.E.-S.W. trending folds with overthrust faults. The ores are concentrated in these overthrust anticlinal fault zones as the matrix of the fault breccias, and in part as replacements of the breccia fragments.

The ore minerals are sphalerite, galena and their secondary products, calamine, smithsonite and cerussite. Nearly all the ores have undergone secondary concentration. The associated minerals, in the order of abundance, are dolomite, calcite, barite, fluorite and quartz. Limonite and manganese ores are frequently associated with lead and zinc ores.

The origin of the ores is ascribed to the leaching by oxidizing waters of lead and zinc minerals widely disseminated through the limestone.

The ore constituents were carried as sulphates and were deposited in their present position as sulphides by the intermingling of solutions and by reaction with carbonaceous materials.

So far the copper production of Virginia has been spasmodic and light. The principal ore minerals are chalcopyrite, chalcocite, bornite, cuprite and native copper. The copper bearing regions are the piedmont plateau, the Blue Ridge, the pyrrhotite gossan area already mentioned in connection with the iron, of the southwest part of the state, principally in Carrol County, and the belts of Triassic sandstones and shales.

The piedmont copper ores are found in bulbous, lenticular quartz veins which are parallel with and also cut across the schist with which they are associated. Near the veins, the schists are altered to epidote, zoisite, chlorite, calcite and iron oxide. The ore is principally chalcocite, bornite and chalcopyrite with minor amounts of cuprite and carbonates.

The copper ores of the Blue Ridge are found in shallow veins in fractured, epidotized basalt forming the core of the ridge. It is believed that the ores are derived from the leaching of the basalt in which the ores are found.

In the past the pyrrhotite gossan region has produced a considerable amount of secondary ore. Most of the work done by the mines now in operation is of an exploratory nature. The ore is found in chalcopyrite stringers in the pyrrhotite veins.

The Triassic sandstones and shales are locally stained with carbonates which present an enticing richness to the eye and have lured many into fruitless mining ventures.

The gold and silver ores of Virginia are found in lenticular quartz veins in the schists of the piedmont. They are associated with a series of interesting minerals, namely, chalcopyrite, pyrite, copper, galena, arsenopyrite, pyromorphite, tetrahedrite, tourmaline, vanadinite, pyrrhotite, siderite and rarely tetradymite. The upper parts only of the veins are free milling. The production has been small and is waning.

Undeveloped but promising *cassiterite* quartz veins with steep dips and greisen walls occur in the Irish Creek district. The granite which they traverse is fissured and faulted and is cut by basalt dikes. Some of the associated minerals are arsenopyrite, pyrite, beryl, siderite, chlorite, muscovite and fluorite. EDWARD STEIDTMANN.

Gold: Its Geological Occurrence and Geographical Distribution. By J. MALCOLM MACLAREN, D.Sc. Royal 8vo, 662 pp., with 1 colored plate, 37 half-tone plates, and 213 illustrations in the text. London, The Mining Journal, 1908. 25s. net.

The main purpose of this handsome, well-printed volume, as stated by the author in a modest preface, is "the presentation in readily acces-

sible form of the salient facts of auriferous deposition." A mere glance through the book with critical attention to arrangement, form of statement and character of references or citations, gives the impression of good workmanship and successful accomplishment—an impression that is fully confirmed by further examination.

Part I, comprising about one sixth of the whole work, is devoted to the origin of gold ores, classification, broad facts of distribution, and other general considerations. Dr. Maclaren has his own views on these subjects and develops them clearly; but, while inclined to accept the general conclusions of which President Van Hise is the chief exponent, he exhibits a mind singularly free from intrenched possession by any one set of hypotheses, and has consistently refrained either from dogmatic assertion or from diminishing the value of his facts by entangling them in the meshes of inference. The reader need have no difficulty in distinguishing the author's conclusions from the vast body of information that he has assembled with skill, candor, and much critical discernment. Dr. Maclaren has visited many of the important goldfields of the world but remarks that, even for those examined, "the facts obtained have in the majority of cases been largely the result of the observations of local geologists, for it rarely happens that a sojourn of a few days on a goldfield results in the acquisition of new, and at the same time accurate information. Often the sole, but by no means unimportant result of personal examination has been the ability to discriminate between the essential and the trivial in the published literature of the given field." This acute and honest observation is the key to much of the excellence of the book and were it taken to heart by other compilers, statements that ought long ago to have been forgotten would not, as now, be perpetuated by uncritical iteration.

Briefly stated, it is the author's belief that the important primary gold deposits of the world have been deposited by originally meteoric water which leached the gold from solid rocks. Magmatic aqueous vapors, if effective at all, are supposed to act as leaching and transporting agents rather than as originally auriferous emanations. Beyond the comment that the evidence pointing to different conclusions is perhaps too lightly regarded by the author, the reviewer is inclined to hasten on to less contentious ground, remarking, however, by the way, that Dr. Maclaren rightly dismisses as valueless the argument that because mines are now dry their ores could never have been deposited by meteoric waters.

Under the heading of *Classification* all schemes based on form of deposit are ruthlessly discarded as of no practical or scientific use. Groupings founded on metasomatic processes or on associations of minerals fare little better, the argument for their rejection being that,

since gold is so easily precipitated in metallic form and yields so few stable compounds, its mineralogical associations, except those with (*a*) sulphides and tellurides in general and (*b*) quartz, are fortuitous, not genetically significant.

While these objections have undoubted force it may be said that classifications serve different ends, and some that admittedly have little to do with genesis nevertheless have value for descriptive purposes, as is illustrated abundantly in the second part of the volume. Classifications of natural objects or processes, moreover, are all more or less tentative and the capacity of any particular grouping to suggest new lines of study or to reveal new truths is determinable only by extended trial. The reviewer believes that we are not justified at the present stage of knowledge in utterly abandoning mineralogical and metasomatic criteria as a means of grouping gold deposits for investigative purposes.

The author proposes to classify the world's gold deposits by "a combination of geographical and geological data, resulting in the establishment of fairly definite auriferous provinces, well separated from each other either in space or in time, or in both." His scheme, which he does not regard as final, is given on the following page.

The grouping illustrated by this synopsis is very interesting and it is in its suggestiveness and stimulus to thought, rather than as a final and accurate expression of truth, that the chief value of such an attempt at broad generalization is most likely to inhere. The genetic dependence of all the first group of the primary class upon the extrusion of andesites or diabase is as yet a very open question and the distinction between the pre-Cambrian and Archean divisions appears in most instances to be decidedly uncertain. While the association of so many of the Tertiary gold deposits with andesite is highly remarkable, gold ores of this period are perhaps not so exclusively or so intimately connected with this rock as Dr. Maclaren's table and text would indicate, although it is only fair to say that he at one place states that in his classification he employs the term "andesitic" merely to designate a type of deposit, which may occur in rock as silicious as quartz trachyte. Cripple Creek, the most productive Tertiary district in the United States is not andesitic. Moreover although important deposits in rhyolite are rare they are not unknown and superficial, pockety accumulations of gold ore in this rock are fairly common. In considering the apparent genetic association between gold and andesite in the Tertiary we need rather stronger assurance than is given that the preponderance of this rock as a gold-bearer over rhyolite, phonolite and trachyte is not due chiefly to its enormously greater abundance. Basalt is of course notoriously barren in spite of the supposed influence of the pre-Cambrian basic dikes on gold deposition.

CLASSIFICATION OF AURIFEROUS DEPOSITS.

Primary.

Connected with the extrusion of intermediate or basic igneous rocks (andesites or diabases) ..... (*a*)	Archean	Schistose rocks: Western Australia (Kalgoorlie, etc.), India (Kolar, Hutti), Rhodesia.
	Pre-Cambrian .	Arising from intrusion of diabase and diorite dykes through Archean schists: Western Australia, India (Dharwar), South Africa (Pilgrim's Rest, Witwatersrand and Barberton), Guianas, Appalachian fields and Eastern Canada.
	Tertiary	Andesitic goldfields: Northern Chili, Peru, Colombia, Mexico, California (Bodie), Nevada, Utah, Colorado, Unalaska, Japan, Sumatra, Celebes, New Zealand, Transylvania.
Connected with the extrusion of acid rocks of granodioritic type.. (*b*)	(?)	Urals.
	Permo-Carboniferous	Eastern Australia and Tasmania.
	Jurassic	Western North America—Alaska, Oregon and California.

Secondary.

Deposits produced or modified by chemical agencies ..... (*a*)	Free gold in original sulphide and telluride veins	(*a*) Arising from decomposition of auriferous sulphides and tellurides by acid waters or by tellurides below the zone of oxidation.
	Placer gold (in part)	(*b*) Arising from decomposition of sulphides and tellurides in the zone of oxidation.
Deposits produced by mechanical agencies... (*b*)	Placer gold (in part)	

Dr. Maclaren lays stress on the conclusion that the great auriferous rocks of the world are the Archean schists and the Tertiary andesites. Between these in geological time is, he remarks, a great gap in gold deposition only "imperfectly bridged by the Permo-Carboniferous gold-veins of eastern Australia and by the middle Mesozoic lodes of California." When, however, the very great importance of these two provinces is taken into account and when, further, attention is turned to the criteria by which many other deposits in metamorphosed rocks have been assigned pre-Cambrian or Archean age, the hiatus does not after all appear so great. The relation between gold deposition and the great periods of volcanicity and intrusion is less fully discussed than many readers will wish.

The distribution of the various groups of gold deposits is shown on an outline map of the world. The Archean schist goldfields are divided into two great metallogenetic provinces: (1) the Erythrean province encircling the Indian Ocean and (2) the Appalachian province skirting the eastern border of the two Americas.

With regard to secondary auriferous deposits the author believes that gold is to some extent taken into solution by vadose waters and that alluvial deposits have in some places been enriched by secondary deposition of gold on nuggets. He considers that the gold of the Witwatersrand banket was introduced by filtration, whereas Gregory[1] has recently added the weight of his opinion to the placer hypothesis.

The natural concentration of gold including the subjects of secondary enrichment and of the occurrence of ore in shoots, is briefly treated. The statement (p. 114) that there is abundant evidence for the existence of a telluride zone of secondary enrichment at Cripple Creek presumably rests upon the brief announcement of that view by Van Hise in his Treatise on Metamorphism. Lindgren and Ransome after thorough study of the district reached the conclusion (cited by Dr. Maclaren on p. 552) that no such enrichment had taken place. A few other statements with reference to this district show that the author has in the first part of his work depended upon literature which in some respects differs from the later investigations in the same field, the results of which may have appeared after Part I. was written. The reference to the prevailing volcanic rock as andesite and the supposed importance of replacement of wall rock by tellurides as given in page 63 are in direct conflict, for example, with the summary on Cripple Creek presented in pages 545–554.

In Part II. the gold districts of the world are reviewed by continents. To comment in detail on this portion of the work would expand this

[1] "The Origin of the Gold of the Rand Goldfield, this JOURNAL, Vol. 4, 1909, p. 118.

review to undue length. It is sufficient to say that the task of compilation and selection has been done with ability and excellent judgment. In general the latest and best literature on each field has been not merely consulted but carefully read and digested. That occasional errors, such, for example, as placing Goldfield, Nevada, on the so-called Amargosa River, should creep into a work of this kind is of course unavoidable. Their number, however, is remarkably small. The references, an important matter in a book of this character, are in general adequate and give the year of publication. In a few instances where a work cited happens to have been written jointly by, we shall say, Smith and Jones the author introduces a quotation by "Smith states that, etc." or reproduces an illustration "after Smith." Such procedure, unfortunately too common, is not only slipshod, but is unjust to Jones, who may himself have written the passages or prepared the illustrations credited in this manner to his colleague alone; the names of collaborators should obviously be used together in every reference to joint work.

The author writes in a clear, straightforward style whose general neatness and accuracy of expression more than atone for occasional lapses, such as the use of what might almost be called the geologist's favorite construction—the hanging present participle. The proofreading and typography are excellent, the paper is good, and the illustrations, mostly modern, are well-chosen and clearly reproduced. There is an index to subjects, a geographical index and an index to authors cited.

Dr. Maclaren is heartily to be congratulated on the production of what is undoubtedly the best general work in any language on the geological and geographical distribution of gold. It is likely to remain a standard for many years.

F. L. RANSOME.

RECENT LITERATURE ON ECONOMIC GEOLOGY.

COMPILED BY

G. F. LOUGHLIN AND J. A. ALLAN.

METALLIFEROUS DEPOSTS.

ALUMINUM.

The Red Zone in the Basaltic Series of the County of Antrim. By G. A. J. COLE. Geol. Mag. Pp. 341–344, 1908. (Short abstract in Geol. Zent., XII., 2, p. 81, 1909.)

The red zone consists of bole, laterite and lithomarge, with pisolitic iron ore towards the top and with bauxite in places just below the upper basalts. The bauxite is believed to be the result of decomposition of rhyolite; the bole, lithomarge, etc., have been derived by tropical weathering of the lower basalt *in situ*. L.

CHROMITE.

The Occurrence of Chromite Deposits along the Southern and Eastern Margins of the Bushveld Plutonic Complex. By A. L. HALL and W. A. HUMPHREYS. Trans. Geol. Soc. S. Africa. Vol. XI., pp. 69–77. Johannesburg, 1908.

Describes occurrence of ore (segregations in basic rocks along margin of a granite area), notes occurrence of platinum in rock and compares with the Russian occurrences. L.

COPPER.

Note on Copper in Andesite near Lautoka, Fiji. By H. I. JENSEN. Journ. R. Soc. N. S. Wales. XLI., pp. 49–55, 1907.

The copper occurs as a mixture of chalcocite and bornite, and is a segregation product in andesite. (Quoted from Geol. Centralb., XII., 6, p. 409, 1909.) L.

Mining on the Queen Charlotte Islands, B. C. By J. E. BLEDSOE. Min. Wld. Vol. 30, No. 12, pp. 527–529, 1909.

States briefly the mining conditions on the Islands. Although no extensive development has as yet been done, yet there is every reason to

believe that copper deposits cover a large area. As the islands are deeply covered with moss and timber it is difficult to work out the geological relations of rocks; however, some of the volcanics are regarded as being of carboniferous age. A.

The Mining Industry in Queensland. By G. W. WILLIAMS. Eng. and Min. Jour. Vol. 87, No. 12, pp. 603–605, 1909.

Describes briefly the locality and the principal mines with the form of ore body in each. The ore bodies occur in the intrusives as stock-works or on the contact between the granite and limestone; sometimes as replacements in the limestone. The writer also describes the process of smelting these lead and copper ores. A.

IRON.

The Clinton Ores of New York. By D. H. NEWLAND. Trans. A. I. M. E. Bi-Mo. Bull. No. 27, pp. 265–283, 1909. (A summary account of the results embodied in Bulletin No. 123, N. Y. State Museum, 1908.)

Outlines extent, stratigraphy, general structure and character of succession of the Clinton beds. Describes occurrence of ore (important ore seams limited to a few areas separated along the strike by lean or barren rock). Describes mining operations. Discusses origin of ore and upholds C. H. Smyth's conclusions: iron derived from Adirondacks and Canadian pre-Cambrian; precipitated from carbonate solution as limonite, either around quartz grains or by replacing shell fragments, in land-locked lagoons; limonite dehydrated by influence of heat and pressure at depth. L.

Das Eisenglimmer am Gleissingerfels. Ein Beitrag zur Geologie und Bergbaugeschichte des Fichtelgebirges. By W. FINK. Geognostische Jahreshefte. XIX. Jg., 1906. Pp. 153–167, with 2 text-figures. München, 1908. (Abstract in Geol. Centralb., XII., 6, p. 410, 1909.)

Historical sketch of mining operations; description of ore occurrence (mostly segregations of specularite in quartz veins with a little pyrite). The origin is attributed to ascending thermal waters, gases and vapors. Vapors of iron chloride, or of a similar compound, reacted with water vapor to form specularite. L.

Zur Genesis des Spateisensteinlagers des Erzberges bei Eisenerz in Obersteirmark. By F. HERITSCH. Mitt. d. Geol. ges. in Wein. I. Bd., 1908, pp. 396–401.

Confirms Redlich's conclusion that the deposit is epigenetic from the additional evidence of siderite veinlets in the rock (a metamorphosed quartz-porphyry) which forms the foot-wall of the ore body. (Geol. Cent., XII., 8, p. 547, 1909.) L.

The Iron-Ore Supply of the United States. By C. W. HAYES. Bull. A. I. M. E. No. 28, pp. 373–379, 1909.

By means of tables gives an estimate of the available supply in the United States and also the available foreign supply. He concludes that within the next thirty years the high-grade ore will have been almost exhausted and a much lower grade of ore will have to be used. A.

Über den Fundort des Magneteisensteins im Berge Wyssokaja im Ural. By F. LOEWINSON-LESSING. Proceedings of the St. Petersburg Polytechnic Institute, 1906. (In Russian, German abstract in the Geol. Centralb., XII., 7, 1909, p. 480.)

The author denies that the magnetite deposit was the result of magmatic differentiation and classifies the ore as a contact deposit of the Banat type. He believes that an effusive feldspathic magma, which broke through the ore, dissolved certain constituents of the latter and developed a peculiar feldspar-magnetite-porphyry. L.

Die Magneteisenlagerstätte des Berges Magnitnaja in der Schaitanschen Datsch im Ural. By N. SMIRNOW. Trav. de la Soc. I., des Naturalists de St. Petersburg, Compt. rend. Vol. 38, livre 1, No. 5–6, pp. 238–252, 1907. (In Russian with an abstract in German.)

The rock formations are serpentine with chromite, amphibolite and pyroxenite with magnetite and gabbro. The evidence all indicates that the magnetite is a typical differentiate from the gabbro magma. (Brief abstract in Geol. Centralb., XII., 7, 1909, p. 479.)

Über die Magneteisenerzlagerstätte des Berges Blagodatj in Ural. By F. LOEWINSON-LESSING. German abstract in the Geol. Cent., XII., 3, 1909, p. 170. Original, in Russian, in the Annals of the Polytechnic Institute of St. Petersburg, VIII., 1907, pp. 1–12.

Discusses occurrence and origin of the ore, formerly regarded as all due to magmatic segregation. In the central portion of the district the brecciated ore was formed by a magnetite magma breaking through syenitic rock. In the southern and northern parts the ore, partly garnetiferous, is associated with strongly metamorphosed syenitic rock. The deposits of the little Blagodatz form a group of lenses in epidotic rock. L.

GOLD.

The Geology of the Gold Fields of British Guiana. By J. B. HARRISON, Director of the Dept. of Science and Agriculture and Govt. Geologist. With historical, geographical and other chapters by F. FOWLER and C. W. ANDERSON. (Reviewed by W. H. E. in Jour. Geol., XVII., No. 2, p. 191, 1909.)

Gives historical sketch, general geology and discusses occurrence and source of the ore. The principal source is the basic igneous rock which,

where relatively fresh, carries from a trace to 17 grains per ton. Concentration *in situ* has resulted through decomposition of the rock to laterite, which are promising low-grade deposits. Further concentration has taken place in some of the stream gravels. L.

Mining Industry of Antioquia, Colombia, S. A. By S. H. WRIGHT. Pt. I., Min. Wld. Vol. XXX., No. 12, pp. 519–523; Pt. II., Min. Wld. Vol. XXX., No. 13, pp. 585–588.

A collection of the information which has appeared on the mines of Colombia. Beside gold there have been found silver, emeralds, iron, copper, lead, tin, zinc, salt, antimony, arsenic, platinum, etc. Describes the auriferous gravels of Antioquia; also the gold occurring in quartz veins and associated in places with mispickel and galena. A.

Placer Gold Mining in Interior Alaska. Eng. and Min. Jour. Vol. 87, No. 12, pp. 591–593.

Gives an interesting account of the general conditions in Alaska, methods of mining and dredging and prospecting. A.

The World's Gold. By L. DE LAUNAY, with an introduction by C. A. CONANT. Translated by O. C. WILLIAMS. New York and London; G. P. Putnam's Sons. Reviewed by W. H. E. in Jour. Geol., XVII., 2, p. 192, 1909.

Arranged for the banker and economist. Future production is the most important subject. Great production predicted for the next fifteen years, followed by decline. L.

GOLD AND COPPER.

The Mount Morgan Gold and Copper Mine. By G. W. WILLIAMS. Eng. and Min. Jour. Vol. 87, No. 13, pp. 635–639, 1909.

Deals especially with the methods employed in mining. These are (1) the open cut with steam shovel, (2) the milling system, (3) square-set supported stopes. One column is devoted to the nature of the ore body. A.

GOLD AND SILVER.

Economic Geology of the Georgetown Quadrangle (together with the Empire District) Colorado. By J. E. SPURR and G. H. GARREY, with General Geology by S. H. BALL. U. S. G. S. Prof. Paper, 63, 1908. Pp. 422, with 87 plates and 155 figures in the text.

Part I. General Geology, pp. 23–96. Part II. Economic Geology. Chap. I. treats of principal ore deposition of Colorado; general features of the ore deposits; features of the earlier silver-lead veins; of the later auriferous pyritic veins; magmatic origin of metals in both groups of veins; zones of ore deposition, localization of ores; nature of fault

movements; Idaho Springs waters, including composition, origin, comparison with other hot springs, and conclusions as to importance of magmatic waters in ore deposition. Chap. II., history and production of mines. Chap. III., detailed descriptions. L.

SILVER.

Geology of the Guanajuato District, Mexico. By C. W. BOTSFORD. Eng. and Min. Jour. Vol. 87, No. 14, pp. 691–694, 1909.

An interesting description of the ore bodies and their genesis. Silver is the principal metal. The oldest rocks are Cretaceous shales which have been penetrated and highly metamorphosed by intrusives. The intrusions have been accompanied by faulting and brecciation. The ore bodies occur as replacement veins along the fault zones, through which the highly heated mineralized solutions ascended. A.

Properties of the Silver King Coalition Co., Utah. By D. MACVICHIE. Min. Wld. XXX., No. 10, pp. 417–421, 1909.

Mentions briefly the occurrence of the ore in the various properties. The ore body is usually found in fissures in quartzite and limestone; in other cases the ore is found between beds of quartzite and limestone, the mineralized solutions having replaced several feet of the limestone on the contact. A.

TIN.

The Origin of Tin Deposits. By J. B. SCRIVENOR. Min. Jour. Vol. LXXXV., No. 3837, p. 307, and No. 3838, p. 340, 1909.

Discusses the formation of tin, dealing at some length with the chemical reactions taking place in its formation. Describes fully the tin deposits of the Federated Malay States, with especial reference to the deposits occurring in limestone.

The writer shows that tourmaline is not necessarily closely connected with the formation of tin deposits, and concludes that flourine is an important reagent in the processes of the formation of cassiterite. A.

VANADIUM.

Vanadium-Deposits of Peru. By D. F. HEWETT. Trans. A. I. M. E. Bi.-Mo. Bull. No. 27, 1909, pp. 291–316, with 15 figures.

Describes two districts in which vanadium deposits have been found, and contains results of laboratory work done to determine the nature of the deposits. The vanadium occurs as patronite ($V_2S_5 + nS$) associated with hydrocarbons (quisqueite and coke) in lens-shaped veins. The patronite is thought to have been the eutectic of the mass. Weathering has developed secondary red, brown and green vanadium compounds of

indefinite formulas. The vanadium is believed to have been concentrated from the surrounding rocks; the source of the hydrocarbons and sulphur are attributed to dikes associated with the deposits. L.

NON-METALLIC DEPOSITS.

CEMENT.

The Action of Frost on Cement and Cement Mortars. By E. R. MATTHEWS and J. WATSON. Proc. A. S. C. E. Vol. XXXV., No. 1, pp. 1–14, 1909.

Describes in detail a series of experiments on the effects of frost, and alternate frost and thaw, on the tensile strength of cement and cement mortar. The results derived from some of these experiments are interesting.

(A discussion of this valuable paper appears in Vol. XXXV., No. 3, pp. 296–301, by W. M. Venable, H. W. Hatton and J. C. Wait.) A.

CLAY.

Clays: Their Occurrence, Properties, and uses with Especial Reference to those of the United States. Second edition, revised. By HEINRICH RIES. Pp. 554; illustrated. 6×9 in., cloth, $5. New York, 1908: John Wiley & Sons; London: Chapman and Hall, Ltd.

Contents: Origin of Clay. Chemical and physical properties of clays. Kinds, methods of mining and manufacture. Distribution in United States. Fuller's earth. A.

Paving Brick and Paving Brick Clays of Illinois. By C. W. ROLFE, R. C. PURDY, A. N. TALBOT and I. O. BAKER. Illinois State Geol. Surv. Bull. No. 9, pp. XIII. and 316, with 3 plates and 33 figures. Urbana, University of Illinois, 1908.

Contents: Geology of clays; qualities of high-grade paving brick and tests used in determining them; qualities of clays suitable for making paving brick; pyro-physical and chemical properties of paving brick clays; clays tested which are suitable for use in the manufacture of paving brick; construction and care of brick pavements. L.

COAL.

Coals of South Wales, with special reference to the origin and distribution of anthracite. By A. STRAHAN and W. POLLARD. Memoirs of the Geological Survey of England and Wales. 8vo. London, 1908. Pp. 78 with 10 plates (including maps and sections). Price 1s., 6d.

Describes sequence of the coal seams, methods of analysis with pos-

sible causes of error, classification of coals, comparison of different bands of the same seam, different samples from the same seam, and of different seams in the same locality. The last chapter deals with the origin of anthracite. The plates include a series of iso-anthracitic maps. (Geol. Centralb. XII., 3, 1909, p. 172.) L.

The Geology of Coal and Coal-Mining. By W. GIBSON. Arnold; London, 1908; 800, pp. 341. Price 1s., 6d.

First volume of Arnold's Geological Series edited by Dr. J. E. Marr. Treats of chemistry and physical characters, formation and origin of coal, index fossils, prospecting and boring, and study of both exposed and concealed coal fields. Later part describes coal fields in various parts of the world. L.

The Great Falls Coal Field in Montana. By A. T. SHURICK. Eng. and Min. Jour. Vol. 87, No. 12, pp. 587–590, 1909.

A brief statement of the geology. Deals especially with general information. It is a bituminous coal and occurs in the Cretaceous. The beds lie practically horizontal. A.

Methods of Mining Coal in New Zealand. By S. FRY. Eng. and Min. Jour. Vol. 87, No. 15, pp. 753–756, 1909.

A description of the equipment and methods of mining, including a brief note on the geology and quality of the coal. A.

Mine Sampling and Chemical Analyses of Coals. Tested at the United States Fuel-Testing Plant, Norfolk, Va., in 1907. By J. S. BARROWS. U. S. G. S. Bull. 362, pp. 23, 1908.

The record of chemical analyses from seventeen localities. Contains much useful data. A.

The Oklahoma Coal Fields. By C. N. GOULD. Min. and Minerals. Vol. XXIX., No. 6, 1909, pp. 275–276.

Describes briefly the probable quantity and value of the coal, also the geology of the fields. It is a fairly good bituminous coal, occurring in numerous seams between the shales and sandstones and varying in thickness from a few inches to seven feet. It is estimated that there are over one billion tons of coal available in these fields which cover less than 500,000 acres. A.

FELDSPAR.

Feldspar Mining in Ontario. By C. MORSACK. Eng. and Min. Jour. Vol. 87, No. 15, pp. 759–760, 1909.

A short description of nature of the deposits; methods of mining; transportation and costs. The feldspar occurs in veins of local origin, from a few feet up to 40 or 50 feet wide, in the Archæn gneissoid granite. These cut across the strike of the schistosity of the granite and mica schists. A.

OIL AND GAS.

A la recherche du petrole en Portugal. By E. ACKERMANN. Bol. Soc. Geog. Lisboa. T. 26, No. 5, 1908, pp. 146–151.

General considerations on the probabilities of finding petroleum in Portugal. (Geol. Cent., XII., 4, 1909, p. 257.) L.

OIL.

A riqueza petrolifera d'Angola. By J. C. DA COSTA. Soc. Geog. de Lisboa, 1908. Pp. 15.

General considerations on petroleum and its extraction; information on eight localities where the presence of bitumen or of petroleum is known. (Geol. Cent., XII., 4, 1909, p. 257.) L.

Das gas- und naptha-führende Gebiet von Surachany. By D. GOLUBJÄTNIKOW. Bull. Com. Geol. St. Pétersbourg, 1908. Bd. 27, No. 3 (Russian with French résumé. German abstract in Geol. Cent., XII., 8, p. 548, 1909).

Mostly a descriptive general geology of the region. Beds of upper miocene age ("Aktschagylschichten") contain white naptha, derived from natural filtration of black naptha which borings prove to exist in lower horizons. Post-pliocene beds, where much faulted, contain naptha and gas. L.

NATURAL GAS.

Natural Gas in Alberta. Can. Min. Jour. Vol. 30, No. 7, pp. 200, 1909.

A short note on the recent explorations of the gas fields in Alberta. The supply of gas is enormous, and the future success of these fields seems certain. A.

WATER.

The Geology and Water Resources of the Great Falls Region, Montana. By C. A. FISHER. U. S. G. S. W.-S. Paper, 221, pp. 89; pts. VII., 1909.

The first third of the paper describes briefly the geography and stratigraphic geology; the last two-thirds describes somewhat fully the water resources and the future supply. It includes tables of data on wells and springs and chemical analyses of the waters. A.

The Pollution of Streams by Sulphite Pulp Waste; A Study of Possible Remedies. By E. B. PHELPS. U. S. G. S. W.-S. Paper, 226, pp. 37, 1909.

Discusses the problem of the utilization of the waste from sulphite pulp mills, which is largely solid organic matter and a very valuable by-product. It is estimated that more than two and a half billion pounds of this waste is annually thrown into the streams. A.

REGIONAL REPORTS.

Die Erzlagerstätten von Pitkäranta am Ladogasee. By O. TRÜSTEDT. Bull. de la Com. geolog. de Finlande, No. 19. Helsingfors, 1907. Pp. 333, with one map, 19 plates and 80 figures in the text (Abstract in Geol. Centralb., XII., 6, p. 409, 1909).

Historical introduction; general geology; relations and genesis of the ores. The author believes the ores to have been introduced by juvenile waters from the Rapakiwi granite magma. They form contact-metamorphic deposits, and are intermediate between the iron-copper type of Kristiana and the copper-tin type of Cornwall. L.

Geology and Mineral Resources of the Laramie Basin, Wyoming. By N. H. DARTON and S. E. SIEBENTHAL. U. S. G. S. Bull. No. 364, pp. 81. Illustrated, 1909.

A preliminary report on the geology and brief mention of the mineral resources which are non-metallic and as coal, clay, gypsum sand, soda, cement, magnesia, etc. L.

ORE DEPOSITS.

Ores Formed by Magmatic Segregation. By F. L. GARRISON. Min. and Sci. Press. Vol. XCVIII., No. 13, pp. 451–456, 1909.

Outlines somewhat fully the definition and scope of magmatic segregation, noting points on which various writers agree or disagree. Some space is given to the part taken by sulphides in such deposits; the writer suggests that sulphides may have been produced by the action of sulphur gases upon native metals in the magma, rather than as being minute particles disseminated through the igneous rocks as held by others. The writer concludes with certain facts of interest from an observation of meteorites. A.

What is an Ore? By J. F. KEMP. Min. and Sci. Press. Vol. XCVIII., No. 12, pp. 419–423, 1909. (Paper read before the Can. Min. Inst., Montreal, March 4, 1909.)

The writer points out the difficulty of defining an ore; he cites the definitions given by various writers, pointing out the weakness of each, and finally suggests a definition which will best suit the term. The writer believes that a distinction should be drawn between the purely scientific use of the word and the technical. A.

UNCLASSIFIED.

The Mineral Wealth of America. By R. W. RAYMOND and W. R. INGALLS. Trans. A. I. M. E. Bi.-Mo. Bull. No. 27, 1909, pp. 248–264.

Sketches history of discoveries of ores in North and South America;

points out that mining of base metals and non-metallic products has been instrumental in establishing permanent mining industries; shows the importance of economic geology in the development of scientific prospecting; discusses fuel resources and emphasizes importance of water power where coal deposits may be lacking. L.

The Professional Examination of Undeveloped Mineral Properties. By C. CATLETT. Trans. A. I. M. E. Bi.-Mo. Bull. No. 27, 1909, pp. 327–335.

Cites several personal experiences and concludes with a suggested outline for a report on an undeveloped mineral property. L.

Tabellarische Ubersicht der technisch nutzbaren Minerale. By A. SACHS. For students of natural history, miners and metallurgists, chemists and engineers. Leipsig and Vienna, Deuticke, 1909. Price 1,50 MK.

Discusses minerals under the following heads: I., Ores; II., coals and hydrocarbons; III., salts; IV., stones and earths. L.

SCIENTIFIC NOTES AND NEWS[1]

THE 218TH MEETING OF THE GEOLOGICAL SOCIETY of Washington was held at the Cosmos Club, on Wednesday, April 14, 1909. The following papers were read: Débris Tracks on the Domes of the Yosemite Region, by F. E. Matthes; Observations on the Recent Calabrian Earthquake, by C. W. Wright.

AT A MEETING of the Western Society of Engineers, April 1, in Chicago, Mr. A. Bement presented a paper on the Illinois coal field, including the results of personal field studies by the author and a summary of the published work of other investigators. The paper was accompanied by statistical data referring to the output of various counties, and of the principal coal seams; and also to the use of powder in the Illinois mines. Maps were presented showing the area of the principal coal seams; their thickness, and the dozen or more centers of the industry in Illinois, with graphic representation of the tonnage output.

The paper was discussed by a number of engineers, among whom were Messrs. W. L. Abbott, D. T. Randall, Geo. S. Rice and R. Y. Williams. Contributing coal operators were Messrs. J. K. Dering and Gordon Buchanan. Mr. F. W. DeWolf discussed the geologic aspects of the work. The original paper, together with the discussions in full, will be published in the next regular bulletin of the Society.

THE WESTERN SOCIETY OF ENGINEERS, through its President, Mr. Andrew Allan, has appointed the following committee to draft a memorial for presentation to the State Legislature, petitioning for the establishment of a department of mines at the Illinois State University: A. Bement, Chairman; F. A. Delano,

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

Bion J. Arnold, John M. Ewen, Isham Randolph, Capt. R. W. Hunt.

THE FOLLOWING PAPER read at the meeting of the New York Academy of Sciences, held on April 5, will be of interest to readers of ECONOMIC GEOLOGY: "A Description of the Two Largest Diamonds Known to History; Their Finding and Ultimate Disposal," by Dr. George F. Kunz.

THE FOLLOWING PAPERS were read at the meeting of the New York Mineralogical Club, on Wednesday, April 14: "The Origin of the Cubic Antigorite and Cubic Dolomite of the Tilly Foster Mine, Tilly Foster, N. Y., and Elsewhere," by Dr. Alexis A. Julien; "Notes on Sequences of the Minerals of the New Jersey Trap," by Mr. Wallace Goold Levison.

THE FOLLOWING PAPERS were read at the meeting of the New York Academy of Sciences, on May 3: "A Recent Exposure in the Serpentine of Staten Island," by Dr. Arthur Hollick; "A New Anthophyllite Occurrence on Manhattan Island," by Mr. H. D. Kinney; "The Moulin Potholes within New York City," by Dr. A. A. Julien; "Observations on the Recent Geologic Changes Affecting the Coast of Ecuador," by Professor M. H. Saville.

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